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BLUElink III Workpackage P4.2 Littoral-Zone Field Program

Nick Mortimer and Graham Symonds

CAWCR Technical Paper No. 065

September 2013

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ISSN: 1836-019X

National Library of Australia Cataloguing-in-Publication entry (pbk)

Author:	Nick Mortimer and Graham Symonds
Title:	Bluelink III Workpackage P4.2 Littoral-zone Field Program
ISBN:	9781486301492 (Electronic Resource)
Series:	CAWCR technical report ; CTR-065,
Notes:	Includes bibliographical references and index.
Subjects:	Coastal biology--Australia--Observations—Mathematical models. Ocean-atmosphere interaction--Australia—Mathematical models. Oceanography--Australia--Observations--Mathematical models.
Dewey Number:	578.751

Cover image courtesy Jean Costa

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1. INTRODUCTION

In Bluelink 2 the development of the Littoral Ocean Modelling System (LOMS) provided a platform to run the littoral zone hydrodynamic model, XBeach. LOMS provides predictions of nearshore waves and currents on the assumption that the bathymetry is immobile. Mean currents are driven by wind and breaking waves and, since wave breaking is a depth-dependent process, bathymetry influences the spatial variability of the mean currents. The mean currents transport sediment stirred into suspension by the waves, modifying the bathymetry which, in turn, alters the distribution of wave breaking and the associated mean current field. In Bluelink 3 LOMS was extended by including morphological changes in responses to time varying waves and currents.

Morphodynamic time scales are typically much longer than hydrodynamic time scales, except perhaps through extreme events, and measuring morphological change under breaking waves is a challenge with conventional hydrographic surveying methods. Long-term, continuous monitoring of morphological change and the nearshore wave field is most effectively done with remote techniques such as video and radar. Video is sensitive to optical properties, for example white water associated with wave breaking, while radar is sensitive to surface roughness associated with breaking waves and surface waves. Both provide slightly different measures of the distribution of wave breaking which in turn serves as a proxy for water depth. Nearshore currents such as rip currents are often associated with an increase in surface roughness due to short waves steepening on the opposing current and are more easily discerned in radar images.

CSIRO has developed the Nearshore Research Facility (NRF) as part of a measurement program using both in-water and shore-based equipment. X-Band radar has proved to be a useful tool for measuring the surface wave field to a range of a few kilometres and can provide continuous data collection during storm events. The X-band radar can also be used to infer bathymetry in a couple of ways; (i) by measuring the distribution of depth induced wave breaking which then provides a proxy for the underlying bathymetry and (ii) by directly measuring the wave speed which is a known function of water depth. An Argus video system has also been included to compliment the capabilities of the radar system. The radar and video data are used to ground truth numerical model hindcasts of morphological evolution on a natural beach.

2. NEARSHORE RESEARCH FACTILITY

CSIRO’s nearshore research facility consists of a number of instruments and platforms that can be used to monitor the nearshore surf zone see Fig 1. The main parts are a lightweight tower with a solar power system capable of supplying up to 300 Watts (peak) and 100 Watts continuously.

The tower currently houses four systems. The Argus video camera array, an ISR X band radar, a Campbell Scientific wind logger and a RTK GPS base station.

To complement the tower the NRF also has the ability to conduct bathymetry and beach surveys using a RTK GPS equipped Personal Water Craft (PWC) in conjunction with a quad motorbike.

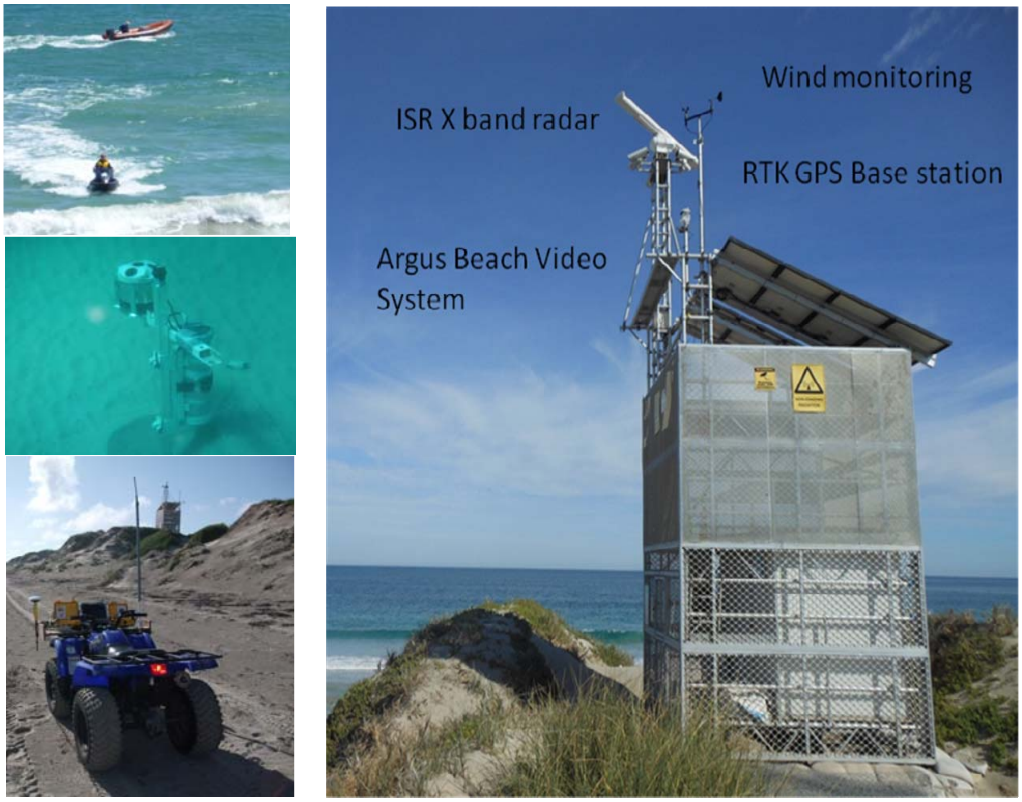


Fig. 1 Parts of CISRO's Nearshore Research Facility (clockwise from top left, Bathymetry survey with PWC, NRF observatory, Beach survey on quad bike, AWAC wave monitoring subsurface mooring.

2.1 Location

The nearshore observatory tower is installed inside Port Kennedy Scientific Park, Lot 216 Port Kennedy Drive. The structure is installed approximately 50m from the water line on top of a 9m high sand dune. The tower is 6m high with a 3m mast on which the radar and Argus video cameras are mounted. The tower is secured to the sand dune using screw piles that are rigidly connected to the structure. The structure has survived a number of storms with wind speeds in excess of 20 ms^{-1} with one event exceeding 30 ms^{-1}. The resolution of video and radar images decreases with distance and assuming a horizontal resolution of 5m or better is needed for quantitative wave observations results in ranges of 500m and 250m for video and radar respectively. The small box around the radar in Fig. 2 shows a box 500m either side of the tower alongshore and 300m offshore indicating the region where pixel time series from video and radar can be used to derive depth. Qualitative information such as sandbar location from time exposure images is observable much further from the tower.

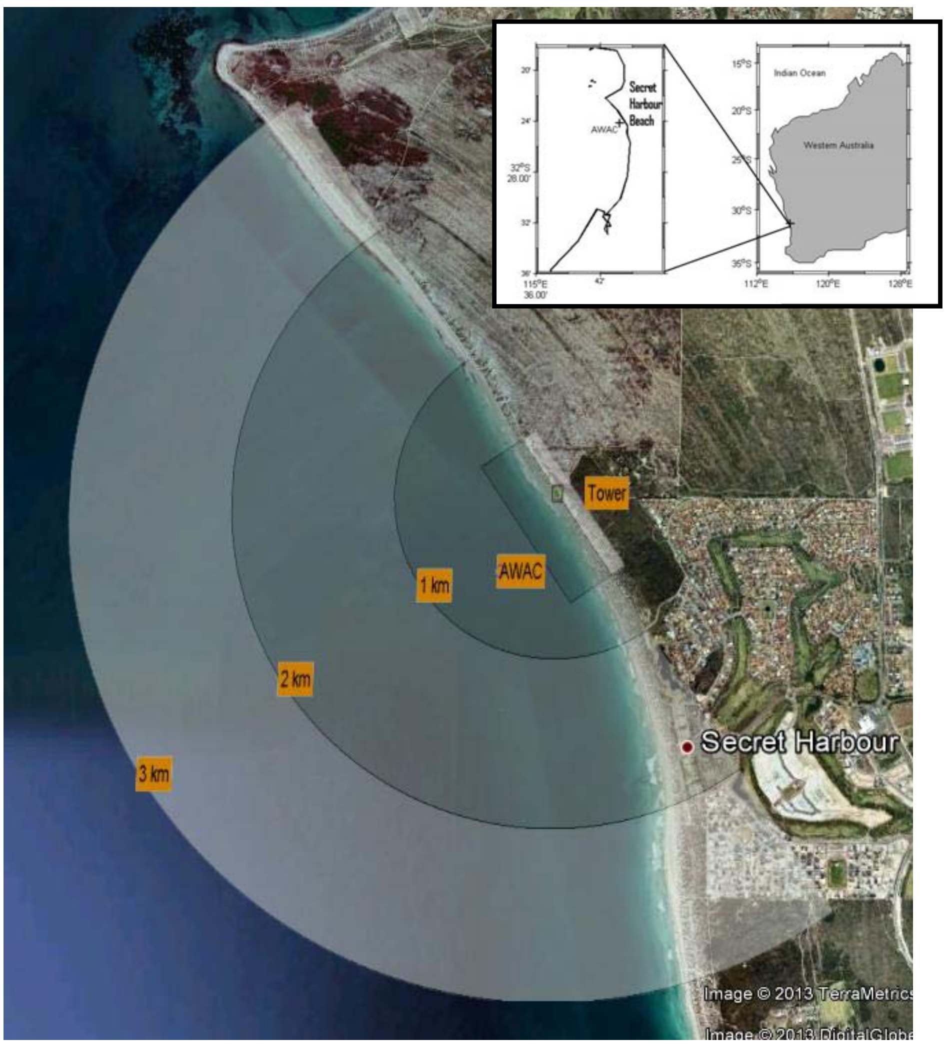


Fig. 2 NRF Location: Lot 216 Port Kennedy Drive - Reserve 44077, Radar range rings with inset Argus monitoring area (rectangle) image courtesy of Google earth

Table 1 lists the positions of the various instruments in both UTM eastings and northings as well as latitude and longitude. A shore normal grid system was constructed to allow data to be used in our modelling effort. The parameters of the grid system are shown in Table 1 along with the computed position of the instruments in the Secret Harbour grid system. The radar position is taken to be the origin of the coordinate system which is then rotated about the origin by 145 degrees (anti-clockwise direction) resulting in a local right-handed coordinate system with the *x*-axis positive offshore and the y-axis positive alongshore.

Table 1 Positions of NRF Instruments and Secret Harbour Grid Details (* negative height is above Australian Height Datum)

Item	*Easting*	*Northing*	*Latitude*	*Longitude*
Radar	381351.92	6415062.49	-32.39516072	115.73847431
Camera 1	381352.38	6415062.14	-32.39516386	115.73847915
Camera 2	381352.12	6415061.98	-32.39516527	115.73847645
Camera 3	381351.38	6415061.94	-32.39516555	115.73846854
Camera 4	381351.24	6415062.13	-32.39516382	115.73846710
Camera 5	381351.47	6415062.82	-32.39515765	115.73846963
Camera 6	381351.72	6415063.00	-32.39515610	115.73847231
AWAC	381017.71	6414580.52	-32.399472	115.734861

Secret Harbour Grid			
False Easing	381351.92		
False Nothing	6415062.49		
Rotation	145		
Item	*X(m)*	*Y(m)*	*Z(m)**
Radar	0	0	-18.81
Camera 1	0.18	0.54	-18.23
Camera 2	0.12	0.53	-18.26
Camera 3	0.75	0.14	-18.24
Camera 4	0.75	-0.10	-18.23
Camera 5	0.17	-0.53	-18.28
Camera 6	-0.17	-0.58	-18.59
AWAC	550.21	203.11	6.8

2.2 Data availability

The data coverage reported here is summarised in Fig. 3, although at the time of writing this report the NRF was still operating. When the observatory was installed in April 2011 only radar and wind instruments were operational. In December 2011 the Argus video system was installed with the help of Rob Holman from Oregon State University. In June 2012 the tower was hit by an intense storm that destroyed both logging computers, hence the large gap. The AWAC unfortunately did not record any data during one of its deployments. The AWAC wave data are well correlated with data from the Rottnest Island wave buoy and can be used to fill data gaps. The NRF data are available on request in various formats; mainly Matlab, NetCDF and Image files (JPEG).

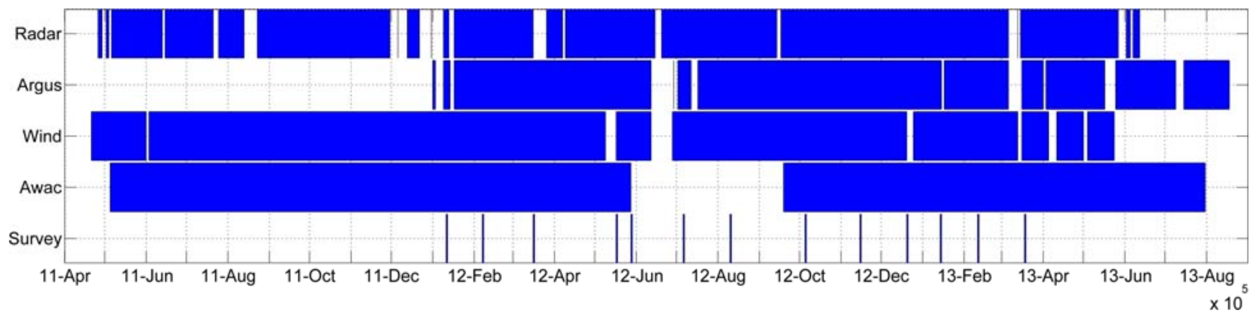


Fig. 3 Data availability from the various instruments

2.2.1 AWAC Wave monitoring

Table 2 AWAC Sampling settings

Current Profile Settings	Value
Profile interval	3600s
Number of cells	20
Cell size	0.50m
Average interval	600s

Wave Burst Settings	Value
Number of wave samples	2048
Wave interval	3600s
Wave sampling rate	2Hz

Monitoring of the nearshore wave field was achieved using a subsurface mooring with a Nortek AWAC (Acoustic Wave and Current profiler) in 8m water depth and 550m offshore. Servicing was undertaken every 3 months to download data, replace batteries and clean. The AWAC collected two distinct datasets, wave properties and current profiles. Table 2 AWAC Sampling settings shows the basic AWAC sampling parameters. The AWAC operates two separate modes, wave burst and current profile. Current profiles were collected every hour with 0.5m vertical bin size. Likewise there was one wave burst per hour. Each sample is the average current over 10 minutes The wave burst consisted of 2048 samples at 2 Hz taking approximately 17 minutes. Data were processed using a combination of Nortek Wavedll and Matlab. Figure 4 shows time series of wave data output from the AWAC. During the summer months (November-April) local sea breezes are common and are reflected in a shift in wave direction towards 220^{o} and a decrease in wave period to about 5s associated with the growth of local wind sea. Over the duration of the project the mean wave height was 0.73m.

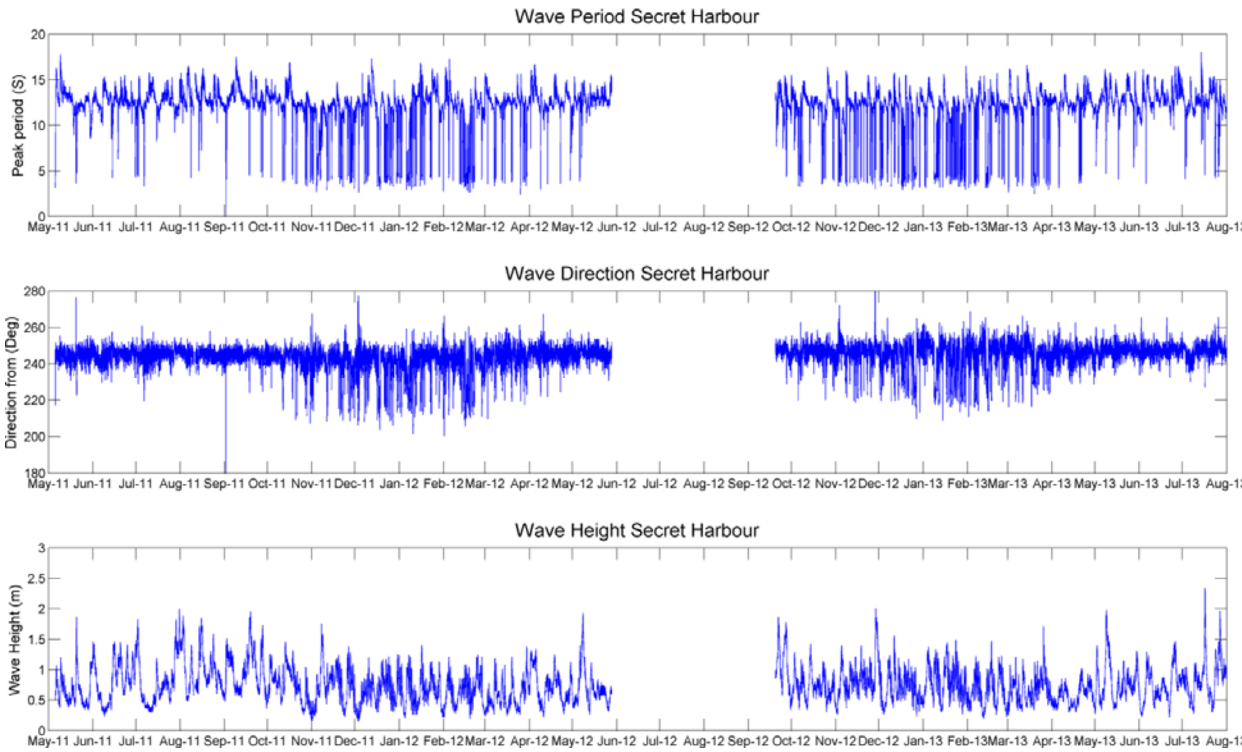


Fig. 4 AWAC processed wave data. Top: wave peak period, Middle: direction, Bottom: wave height

2.2.2 Argus Video System

The Argus beach video system consists of six high resolution video cameras. Each camera has a fixed lens either 12.5mm or 8mm (see Table 3). The high resolution cameras and focal lengths were chosen to offset the decrease in resolution associated with the relatively low elevation of the cameras. The cameras and lenses are positioned to give a 200+ degree view of the beach.

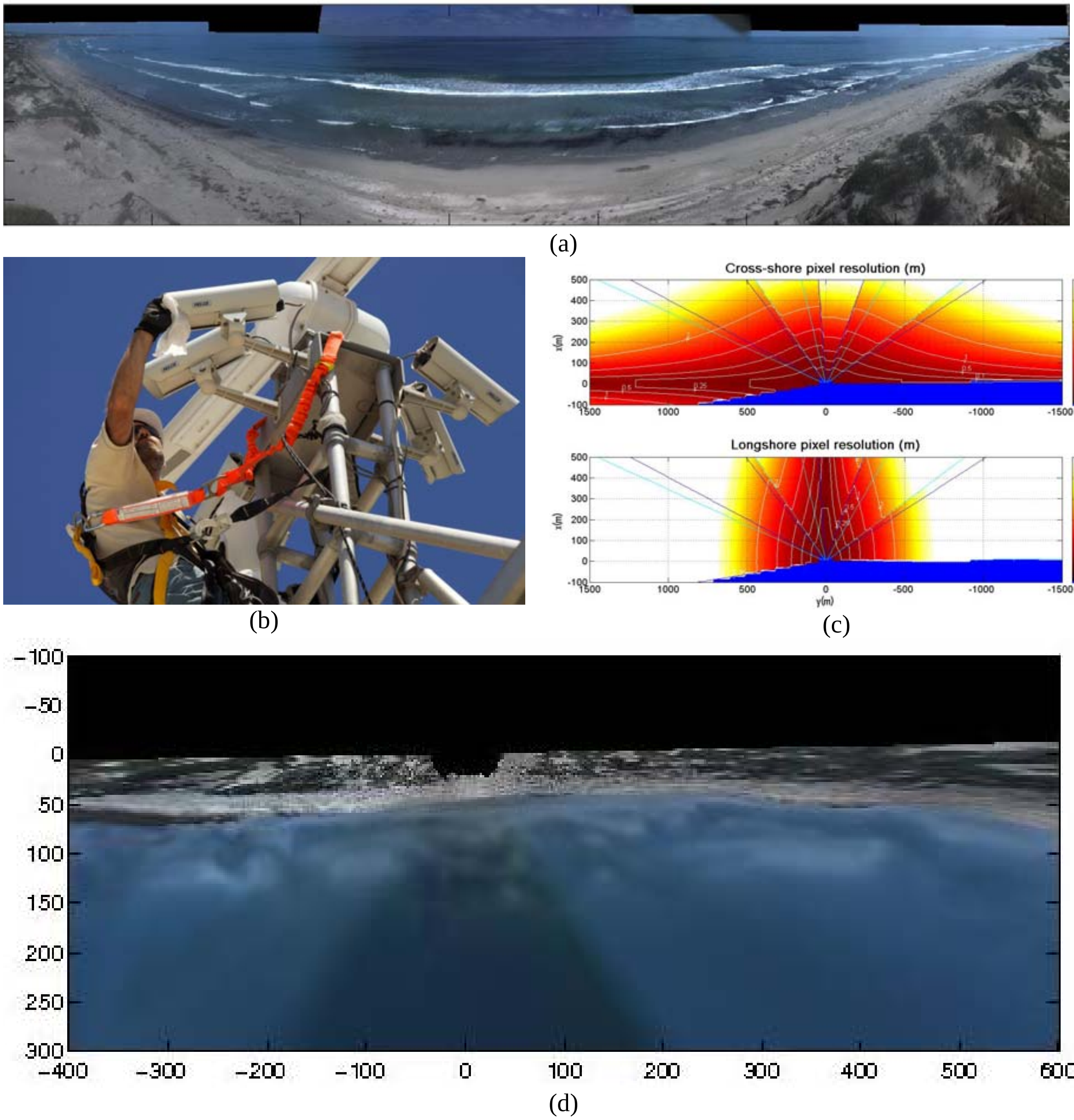


Fig. 5 Argus beach video system: (a) image from 6 cameras stitched together, (b) maintenance work on cameras, (c) pixel resolution map, (d) rectified time exposure image.

Table 3 Argus camera detail

Camera Details	
Manufacturer	Point Gray:GRAS-50S5C-C
Image sensor	Sony ICX625 CCD, 2/3", 3.45 µm
Resolution	2448x2048 at 15 FPS

Lens Details					
Camera 1	Camera 2	Camera 3	Camera 4	Camera 5	Camera 6
Fujinon 12.5mm Sn.478111	Fujinon 12.5mm Sn.478090	Pentax 8mm Sn.76147	Pentax 8mm Sn.76077	Fujinon 12.5mm Sn.478097	Fujinon 12.5mm Sn.478042

Figure 5a shows a panorama image stitched together. Figure 5b shows maintenance work being carried out on the camera array. Figure 5c shows maps of pixel size for each camera in the local coordinate system with x positive offshore and y positive alongshore. The alongshore pixel size is about 5m at a distance of 500m from the cameras while the corresponding cross-shore pixel size is less than 2m. These elongated pixels result from the relatively low elevation of the cameras and Fig. 5c provides some guidance on the limits of quantitative observations such as shoreline location and pixel time series analysis used to estimate depth. The cameras take successive images at the rate of 2 frames per second for approximately 10 minutes every two hours during daylight. Data is stored in two main forms: images and pixel time stacks. The types of images are shown in Fig. 6. The Snap image is a single frame and is useful for assessing the surf conditions as well as the quality of the image path. The time exposure image averages out the incident waves to reveal areas of depth induced wave breaking, useful for monitoring beach morphology. The other three images are statistically derived, from the variance of each pixel and the maximum and minimum intensity of each pixel. Along with the images pixel time series are stored from a pre-computed grid. These time stacks can be used for further analysis such as depth retrieval


Snap image


Time exposure image


Variance pixel image


Brightest pixel image


Darkest pixel image

Fig. 6 The five types of Argus images

2.2.3 Bathymetry Surveys


(a) Echo Sounder

(b) Survey Personal Water Craft


(c) Survey display

Fig. 7 Personal Water Craft (PWC) survey system

In order to ground truth the radar and video derived depth and time exposures monthly bathymetry surveys were completed using a Personal Water Craft (PWC) equipped with depth sounder and RTK GPS as shown in Fig. 7. Beach surveys were done with the RTK GPS mounted on a quad bike (see Fig. 1).

In order to achieve the required accuracy surveying is done using real time kinematic (RTK) GPS. An RTK GPS system consists of two parts: a base station which is located on the observatory and a rover unit on the PWC. The base station has been previously surveyed in from a known point (see Appendix 3) and because its position is known it can estimate the error for each satellite in view. These error corrections are then transmitted via a UHF data link to the rover unit. The rover unit can then calculate the GPS antenna height with an accuracy of approximately 1cm. The tide correction can be calculated as shown in Fig. 8. Most of the bathymetry surveys are conducted on days of low wave height and the operator tries to ride toward the shore behind a wave crest to minimise heave of the PWC.

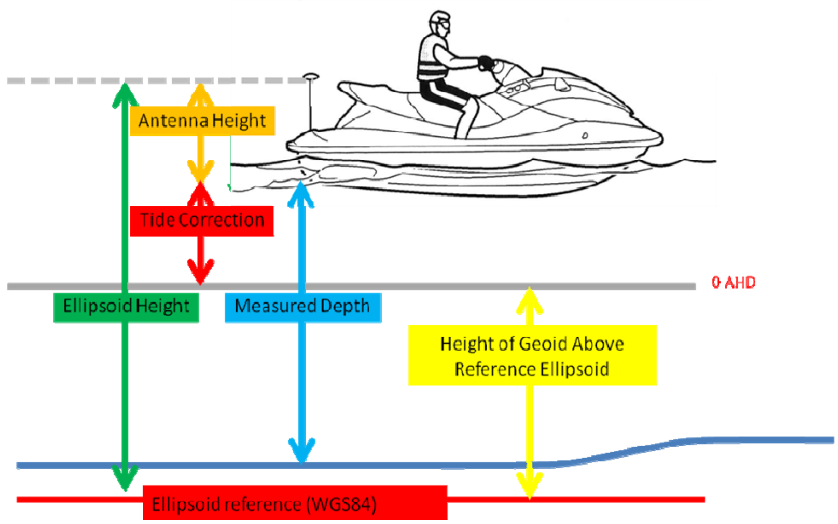


Fig. 8 Tidal height calculations

Figure 9 shows a comparison of successive surveys along a common cross shore transect. The shore line is to the left of the figure. The black dots show data from a LiDAS Survey at the same location (Department of Transport - Coastal Information Business Unit. (2009) *Two Rocks to Cape Naturaliste - LiDAR Bathymetric and Seabed Survey* [Data Set]. Fremantle, Western Australia). As can be seen the majority of variation takes place in less than 3m water depth.

Results from 11 surveys completed between February 2012 and February 2013 are shown in Fig.10 where the bathymetry contours are overlaid on corresponding time exposure video images from within a week of the survey. The white areas in the time exposure images correspond to regions of depth induced breaking and so provide a proxy for the underlying bathymetry which, qualitatively agree with the surveyed bathymetry contours.

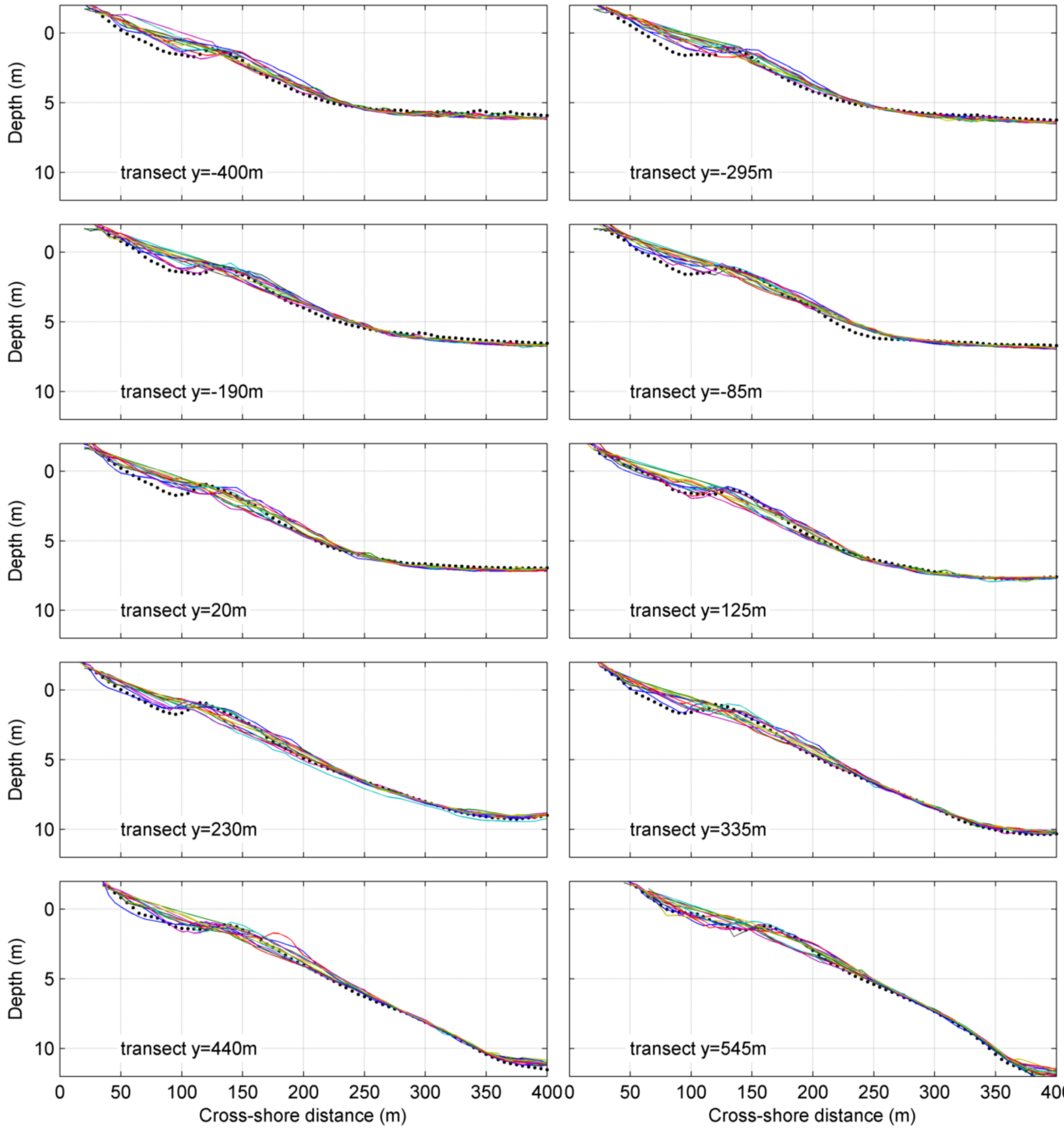


Fig. 9 Comparison of multiple surveys at selected cross shore transects (coloured lines are PWC surverys, black dots are LiDAS Survey)

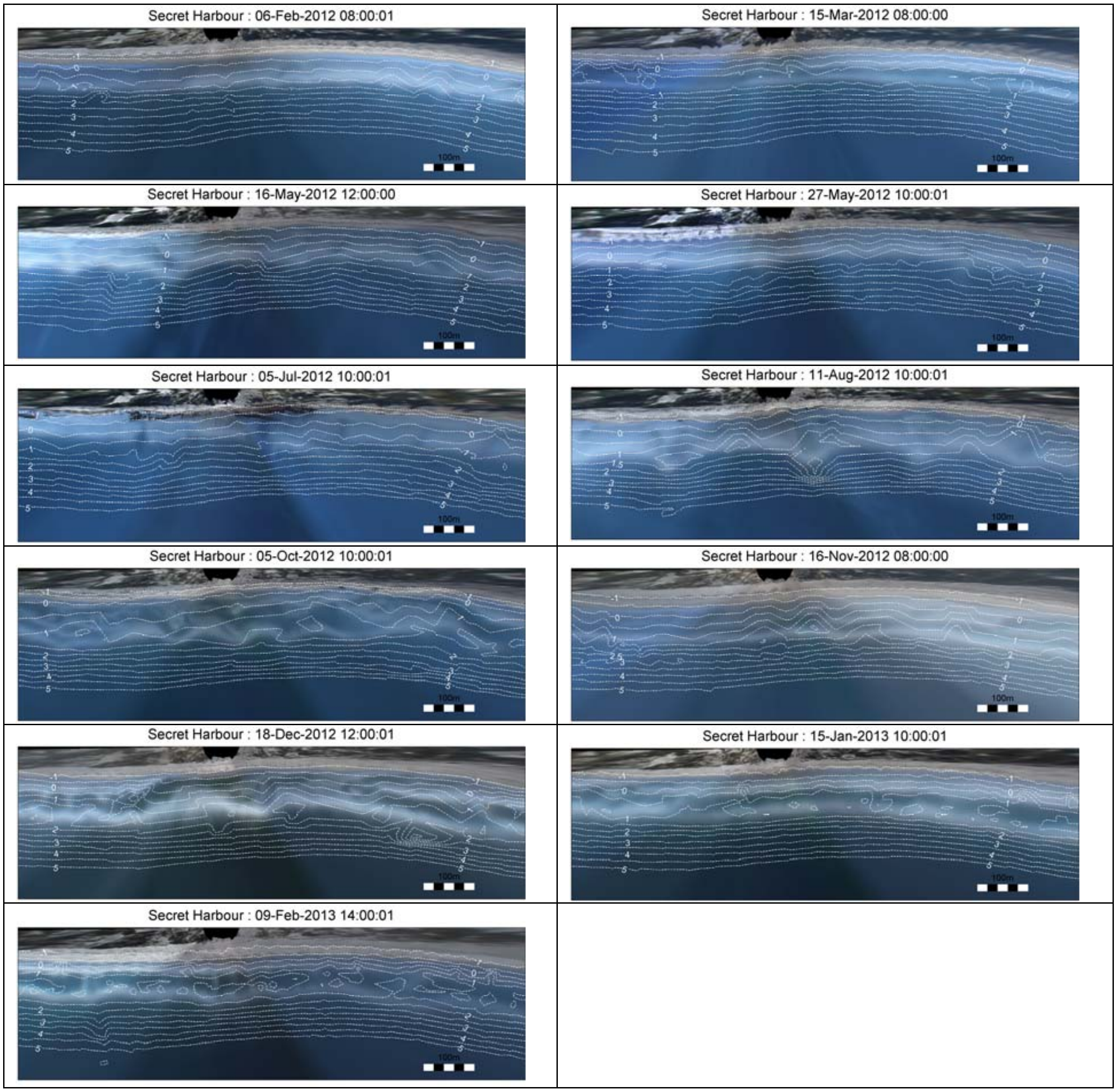


Fig. 10   Bathymetry Surveys (contour) over Argus time exposure images

2.2.4 Wind monitoring

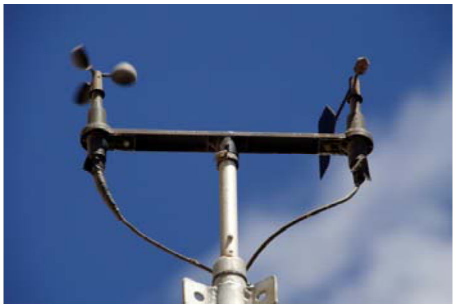


Fig. 11 R.M. Young Wind Sentry

Wind direction and speed were logged using an R. M. Young Wind Sentry Set in conjunction with a Campbell Scientific CR200X data logger. See Table 4 for full details of the system.

Table 4 Wind logging system

Data Logger	
Model	Campbell Scientific:CR200X
Sample interval	60s
Wind sensor	R. M. Young Wind Sentry Set and Anemometer

Wind Speed	
Range	: 0 to 50 m s^{-1} (112 mph)
Gust Survival	60 m s^{-1} (134 mph)
Sensor	12-cm diameter cup wheel assembly, 40-mm diameter hemispherical cups
Accuracy	±0.5 m s^{-1} (1.1 mph)

Wind Direction	
Range	360° mechanical 352° electrical (8° open)
Sensor	Balanced vane; 16 cm turning radius
Accuracy	: ±5°
	10° Displacement 0.8 m s^{-1} (1.8 mph)
	5° Displacement1.8 m s^{-1} (4 mph)
	:

Time series of eastward (U) and northward (V) components of wind velocity are shown in Fig. 12. The strongest winds are associated with winter storms, but during summer sea breezes wind speeds regularly exceed 10 ms^{-1}.

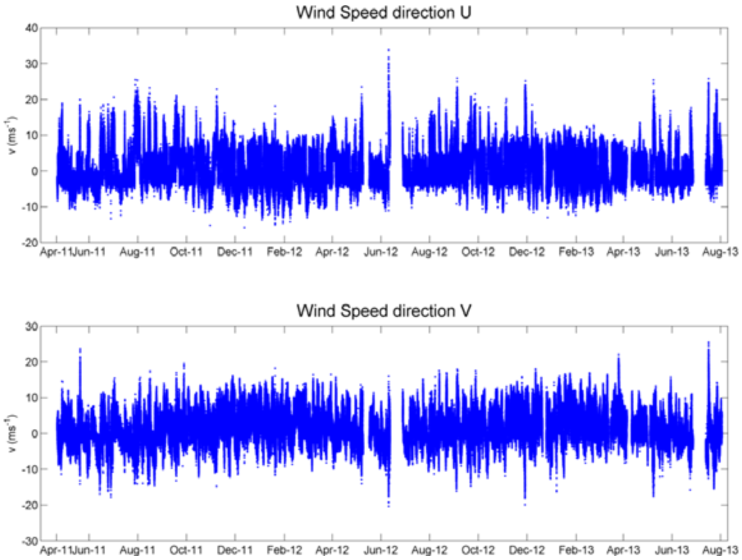


Fig. 12 U and V Wind speed from Nearshore Observatory

2.2.5 X-Band radar system

The radar system supplied by Imaging Science Research Inc. (ISR) is based on a Koden MDS-63R RADARpc with the addition of a personal computer with a high speed analogue capture card and custom software. See Table 5 for full details of the system. The radar operates at the standard X band frequency of 9.8 GHz. At this frequency the wave length is approximately 3cm and is reflected off small capillary waves on the ocean surface with approximately the same wave length by a process called Bragg scattering. The strength of the reflected signal is modulated by longer surface gravity waves in a nonlinear process mainly due to three effects:

- Hydrodynamic modulation, the interaction between small capillary waves and the longer surface waves.
- Tilt modulation, due to the change in effective incidence angle along the wave slope.
- Shadowing of the sea surface behind wave crests due to the height of the waves.

Time series of images are collected over a period of 20 minutes every two hours. An advantage of the radar over video is that it collects data through the night.

Table 5 Radar Details

Radar	
Model	ISR DIR 25.9
Transmit frequency	9.8 GHz
Transmit pulse length	80 nS
Pulse repetition frequency	2000 Hz
Duty cycle	0.00016
Rotation Period	1.25 seconds (48 rpm)
Antenna	9 foot open scanning array (2.74m)
Horizontal beam width	0.8°
Vertical beam width	25°
Gain	30 dB

Sampling Details	
Antenna Height	16.8m.
Rotations per sample	1029
Total sampling time	22 mins
Samples per day	12 (every 2 hours)

Maps of cross-shore and alongshore pixel size are shown in Fig. 13. These maps show the size of the pixels in the local coordinate system, x cross-shore and y alongshore. The cross-shore size of the pixels increase quite quickly alongshore due to the horizontal spreading of the beam while the alongshore resolution remains relatively uniform because the radial bin size is a constant due to the fixed length transmit pulse.

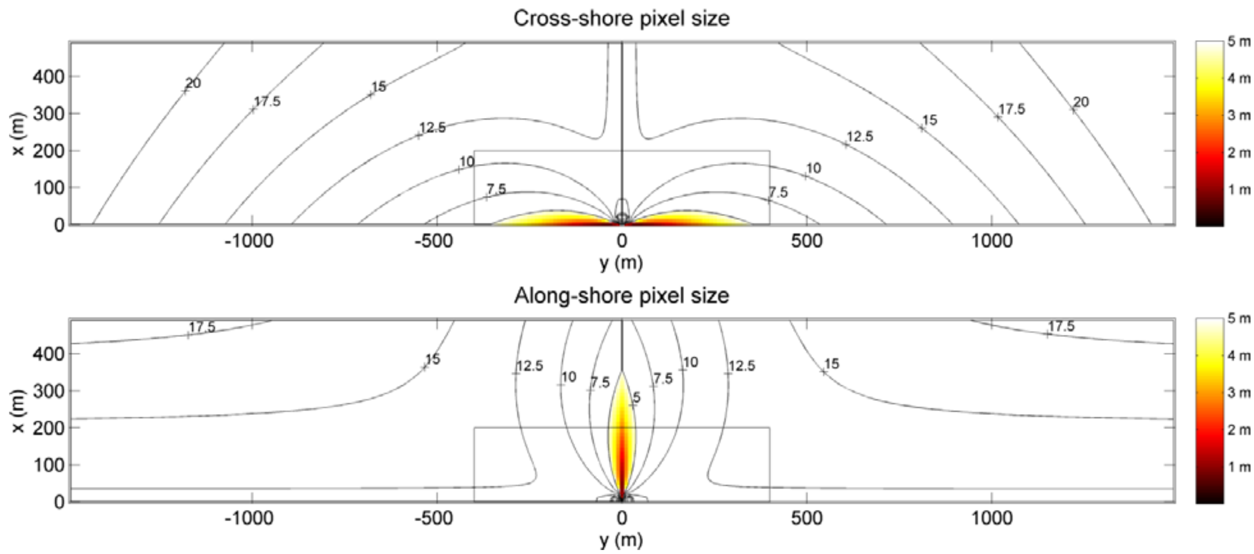


Fig. 13 Maps of cross-shore (top) and alongshore (bottom) pixel size in the local coordinate system with x positive offshore and y positive alongshore.

A radar snapshot (one rotation) of the sea surface is shown in Fig. 14(a) where the wave crests are clearly visible. The other panels in Fig. 14 are time exposure images (averaged over all rotations in a 22 minute run). These images are similar to video time exposures and reveal the average distribution of depth induced wave breaking and hence provide a proxy for water depth. However, the radar time exposure images also detect areas of increased surface roughness often associated with rip currents which appear as plumes exiting the surf zone as shown in the panel of Fig. 14(c). Figure 14(d) shows a relatively alongshore uniform sandbar which are common along many of Perth's metropolitan beaches especially in summer.

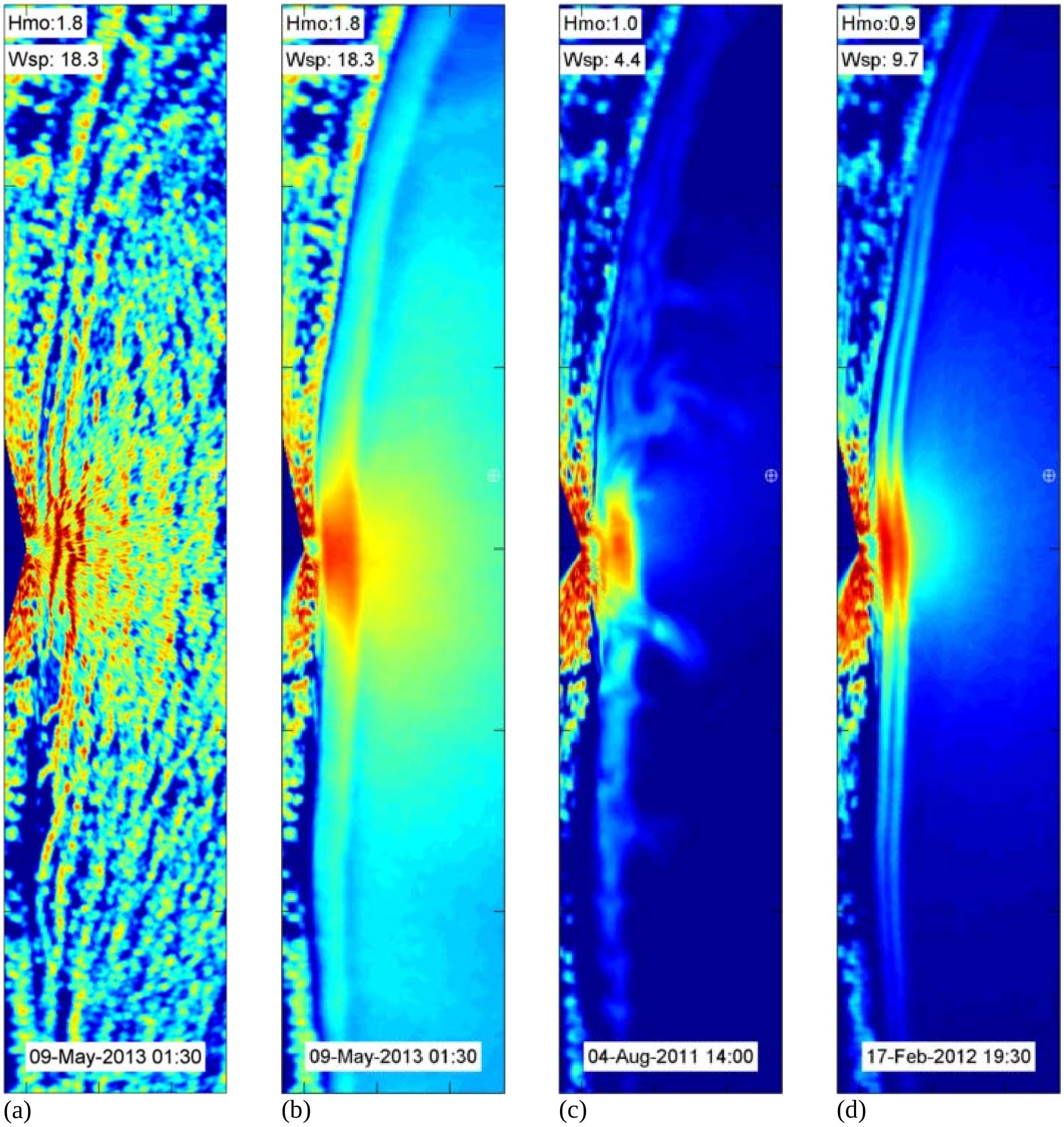


Fig. 14 (a) single snapshot of the sea surface, (b) time exposure of same time, showing wide surf zone, (c) time exposure image showing rip current plumes, (d) time exposure image showing an alongshore uniform sandbar.

3. ACKNOWLEDGMENTS

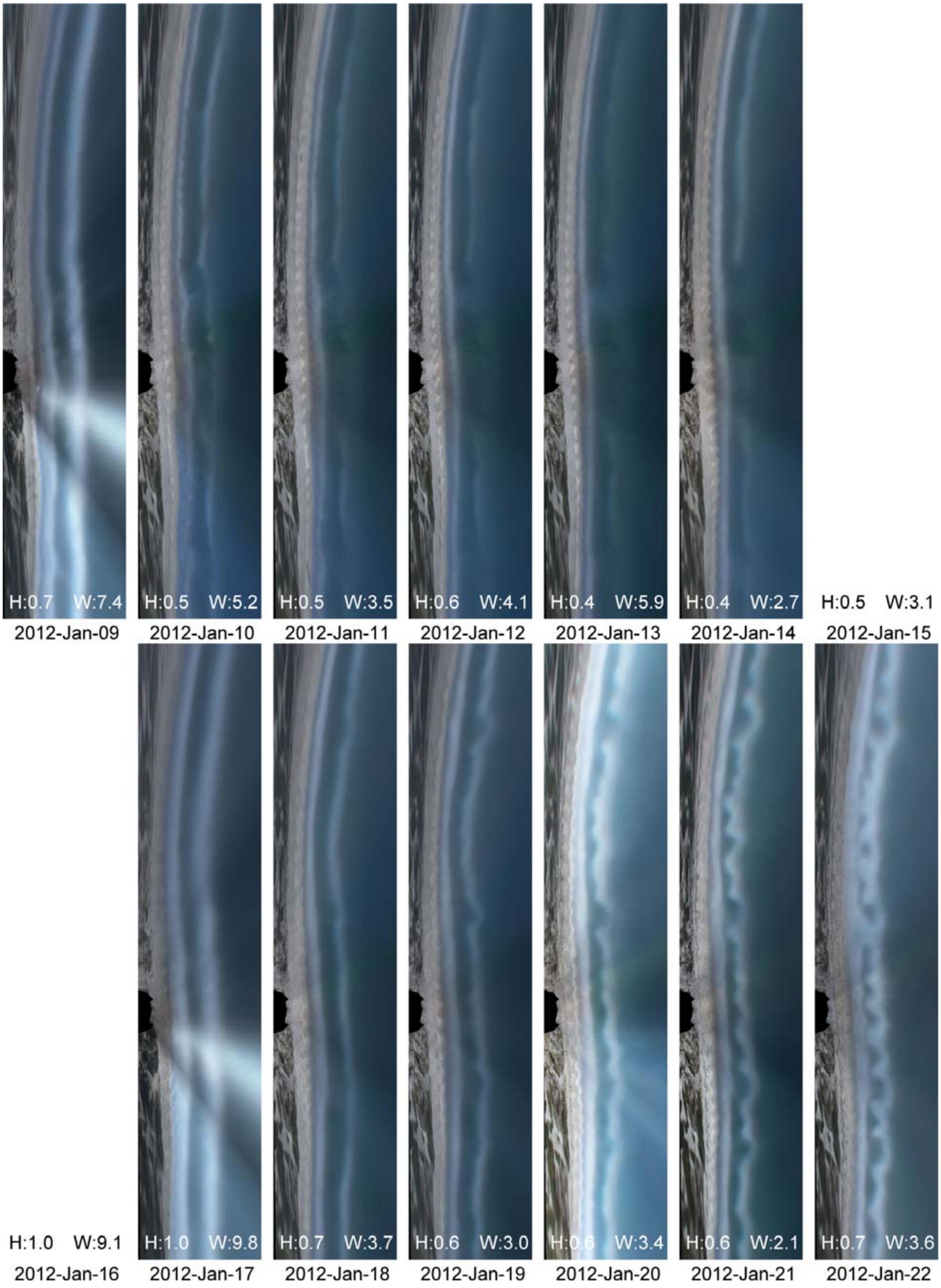
The authors would like to thank the following for their invaluable support in all field operations: Stelios Kondylas, Ryan Crossing, James McLaughlin, Corey Stokes, Jim Gunson, Stephanie Contardo. Also Rob Holman and John Stanley from Oregan State University for helping install and operate the Argus beach video monitoring system. Photographer Joan Costa for the cover image.

APPENDIX 1 ARGUS IMAGES

Daily rectified and merged time exposure video images in a region extending 300m offshore and 1000m alongshore.

H:0.6 W:6.2	H:0.6 W:5.0	H:0.6 W:3.2	H:0.5 W:2.7	H:0.4 W:2.5	H:0.7 W:3.0	
2011-Dec-26	2011-Dec-27	2011-Dec-28	2011-Dec-29	2011-Dec-30	2011-Dec-31	2012-Jan-01

		H:0.4 W:8.7	H:0.3 W:2.8	H:0.5 W:6.4	H:1.0 W:9.7	H:0.8 W:5.8
2012-Jan-02	2012-Jan-03	2012-Jan-04	2012-Jan-05	2012-Jan-06	2012-Jan-07	2012-Jan-08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2012-Jan-10
H:0.5 W:3.5
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H:0.6 W:4.1
2012-Jan-12
H:0.4 W:5.9
2012-Jan-13
H:0.4 W:2.7
2012-Jan-14
H:0.5 W:3.1
2012-Jan-15
H:1.0 W:9.1
2012-Jan-16
H:1.0 W:9.8
2012-Jan-17
H:0.7 W:3.7
2012-Jan-18
H:0.6 W:3.0
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2012-Jan-20
H:0.6 W:2.1
2012-Jan-21
H:0.7 W:3.6
2012-Jan-22

2012-Jan-23

2012-Jan-24

2012-Jan-25

2012-Jan-26

2012-Jan-27

2012-Jan-28

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2012-Jan-30

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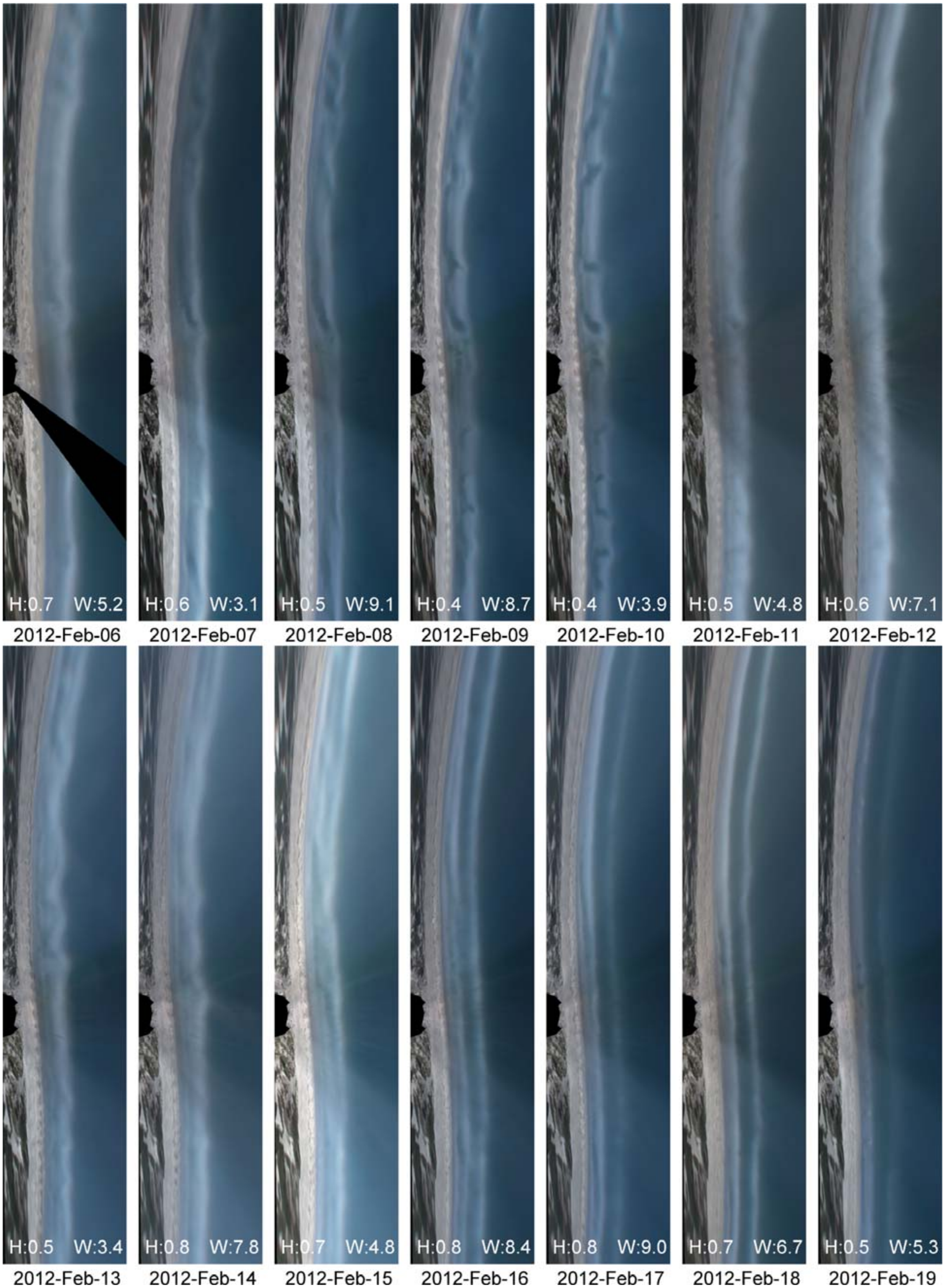
2012-Feb-03

2012-Feb-04

2012-Feb-05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2012-Feb-10
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H:0.8 W:8.4
2012-Feb-16
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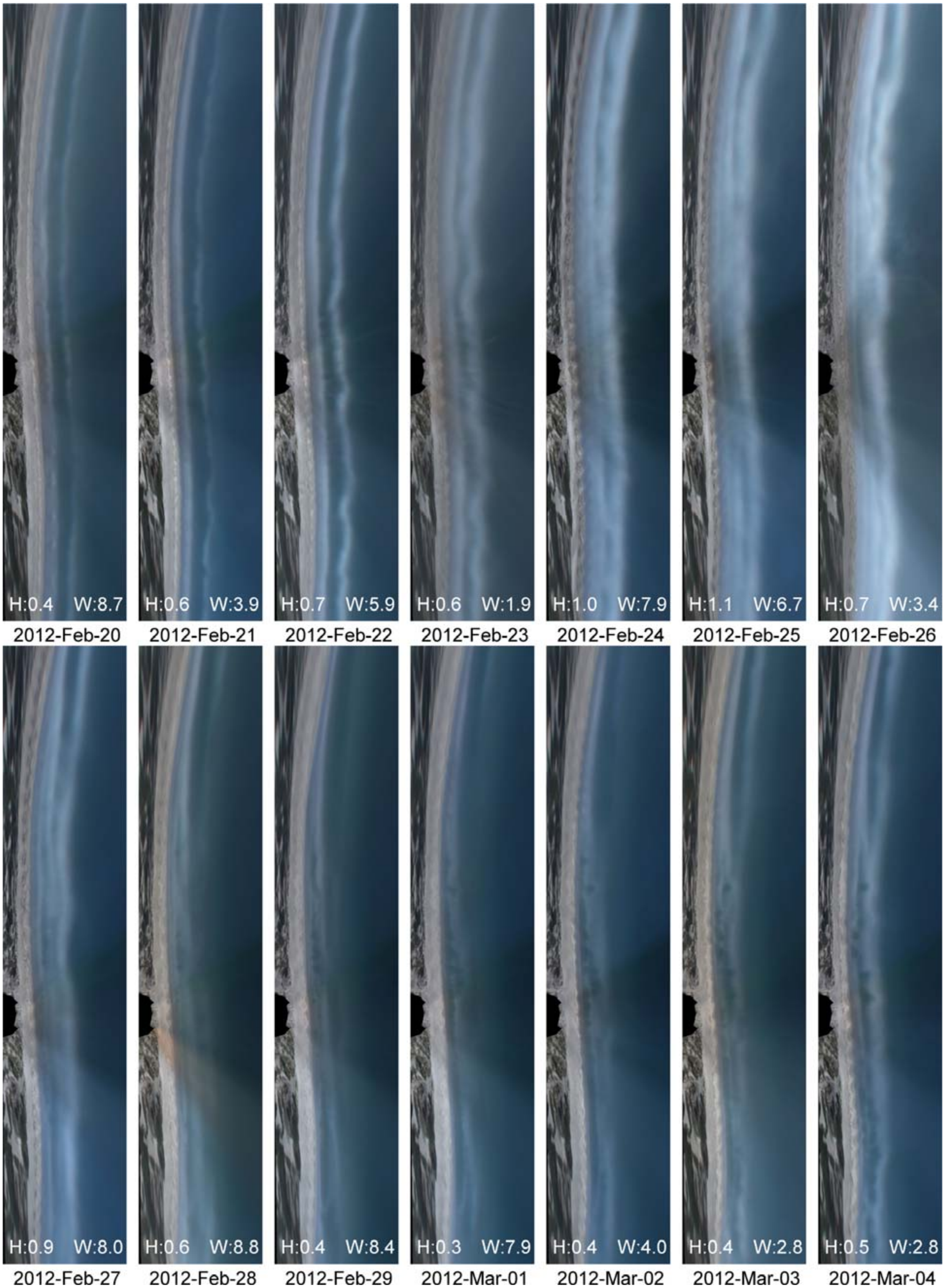
2012-Feb-19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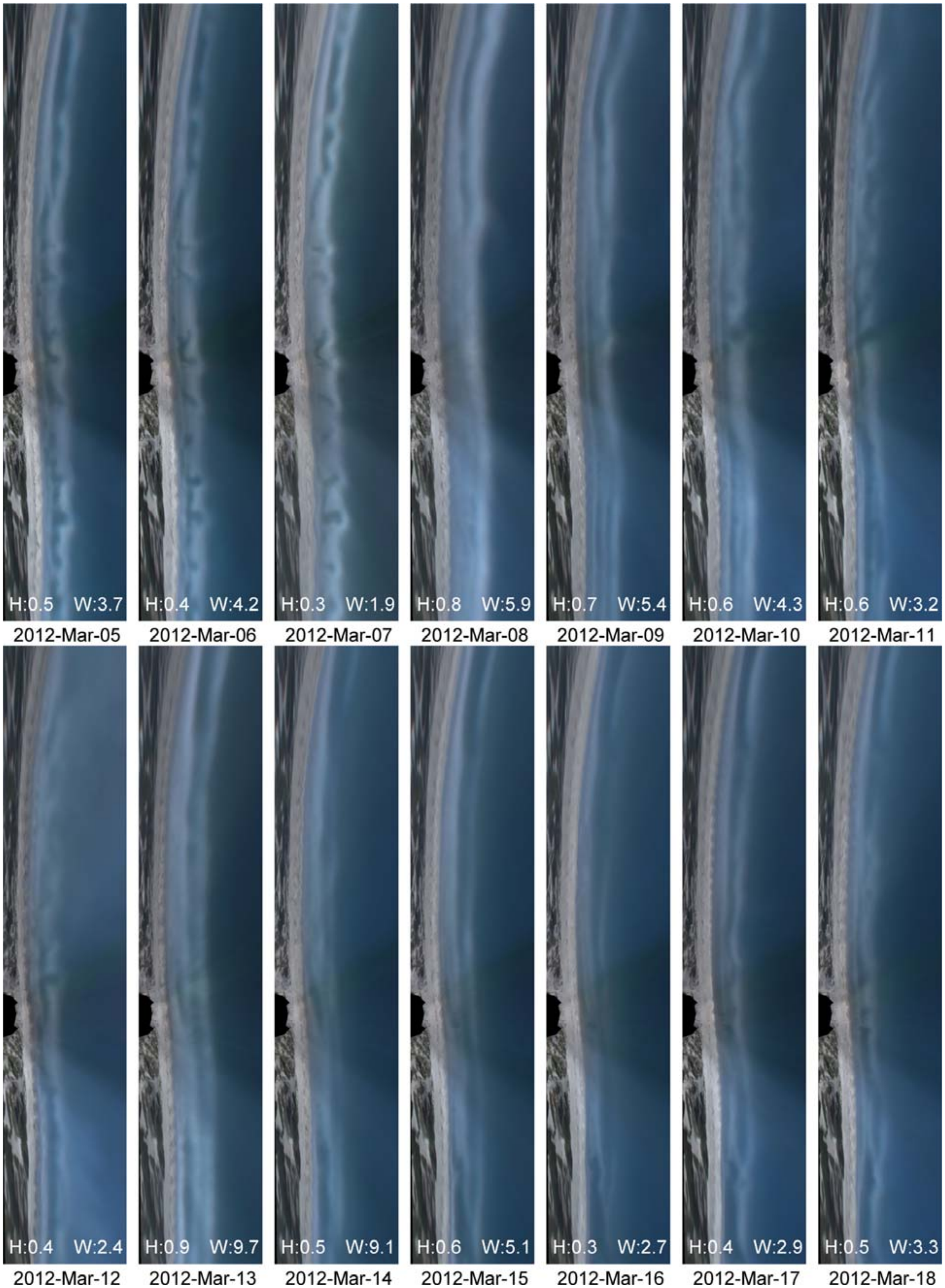
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2012-Mar-11
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2012-Mar-12
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2012-Mar-13
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2012-Mar-14
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2012-Mar-15
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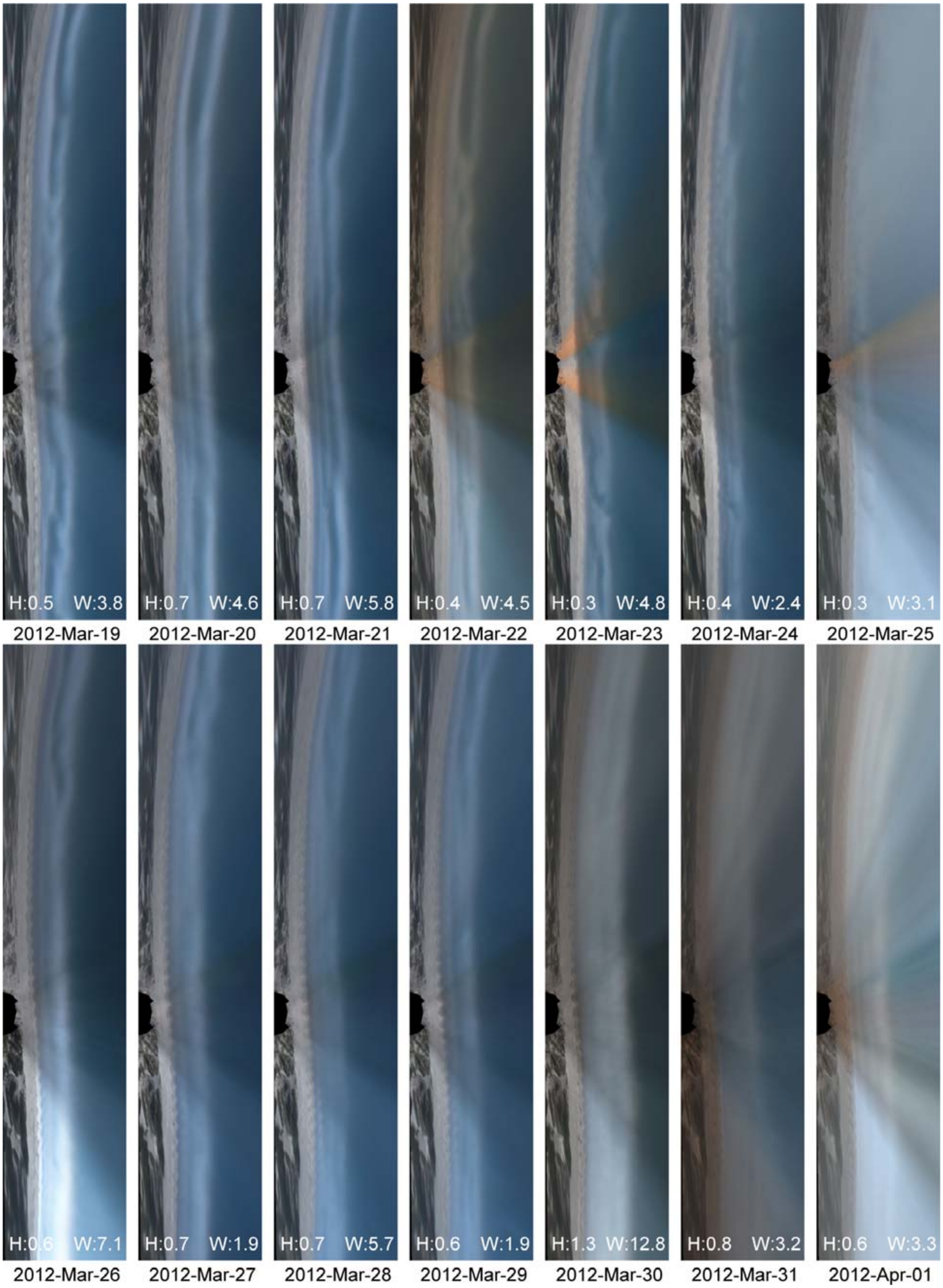
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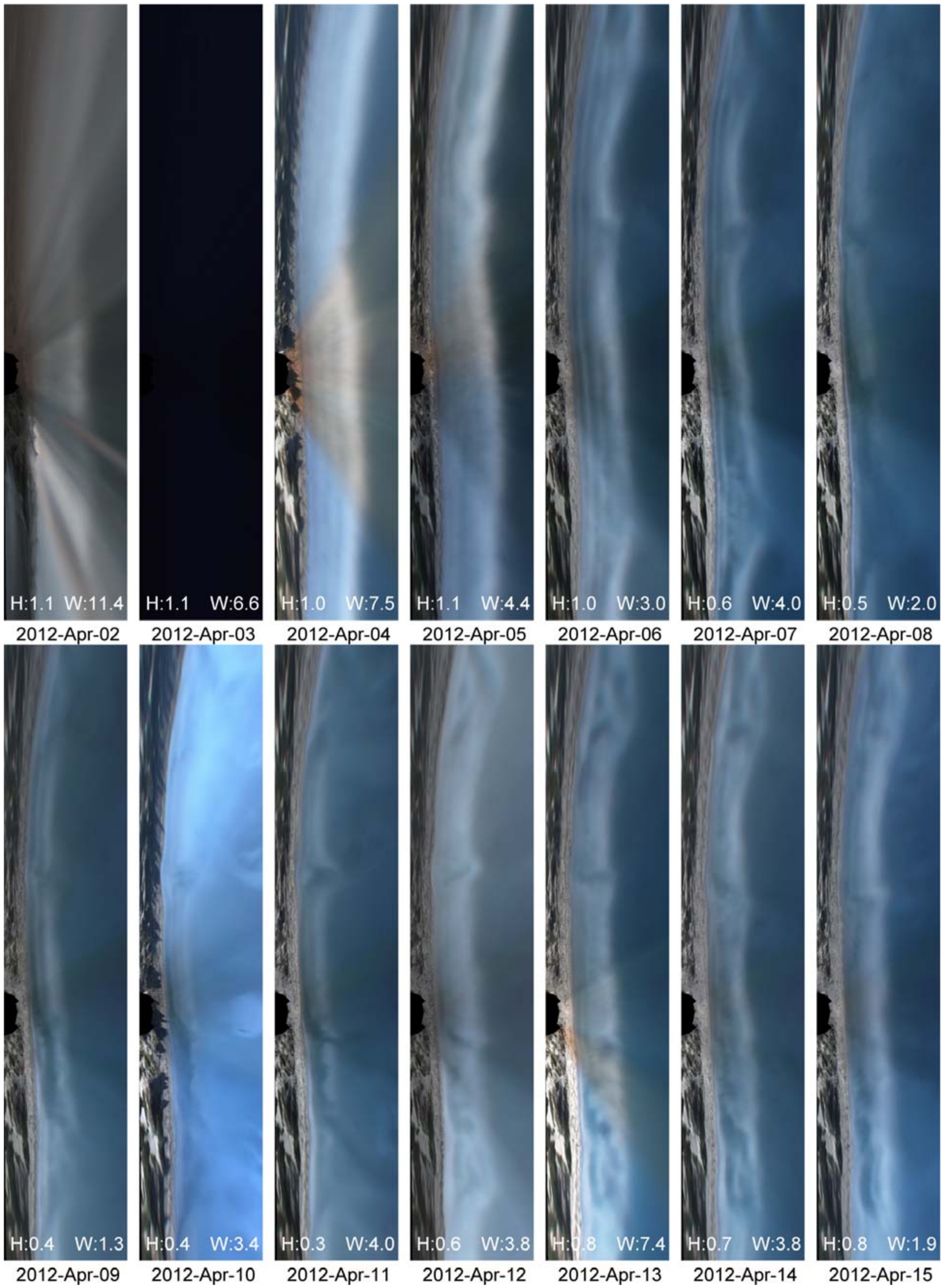
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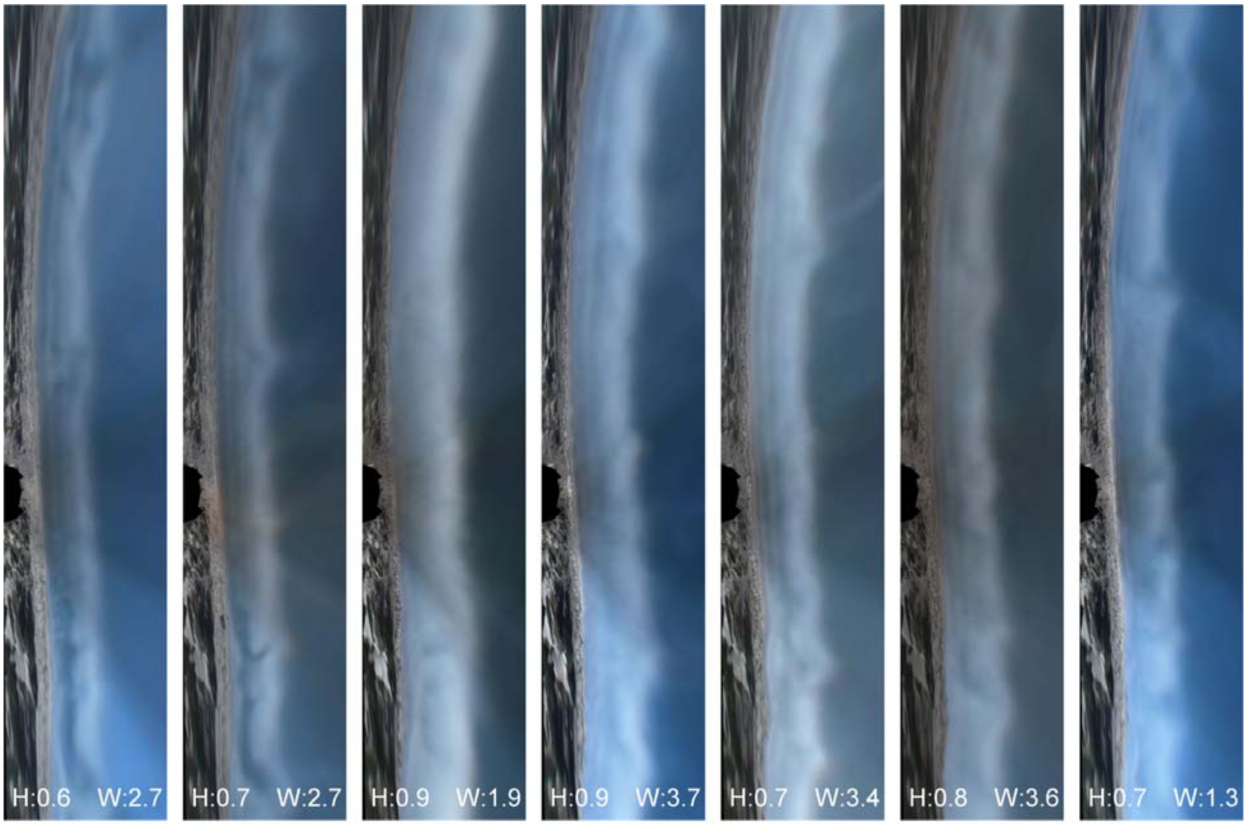

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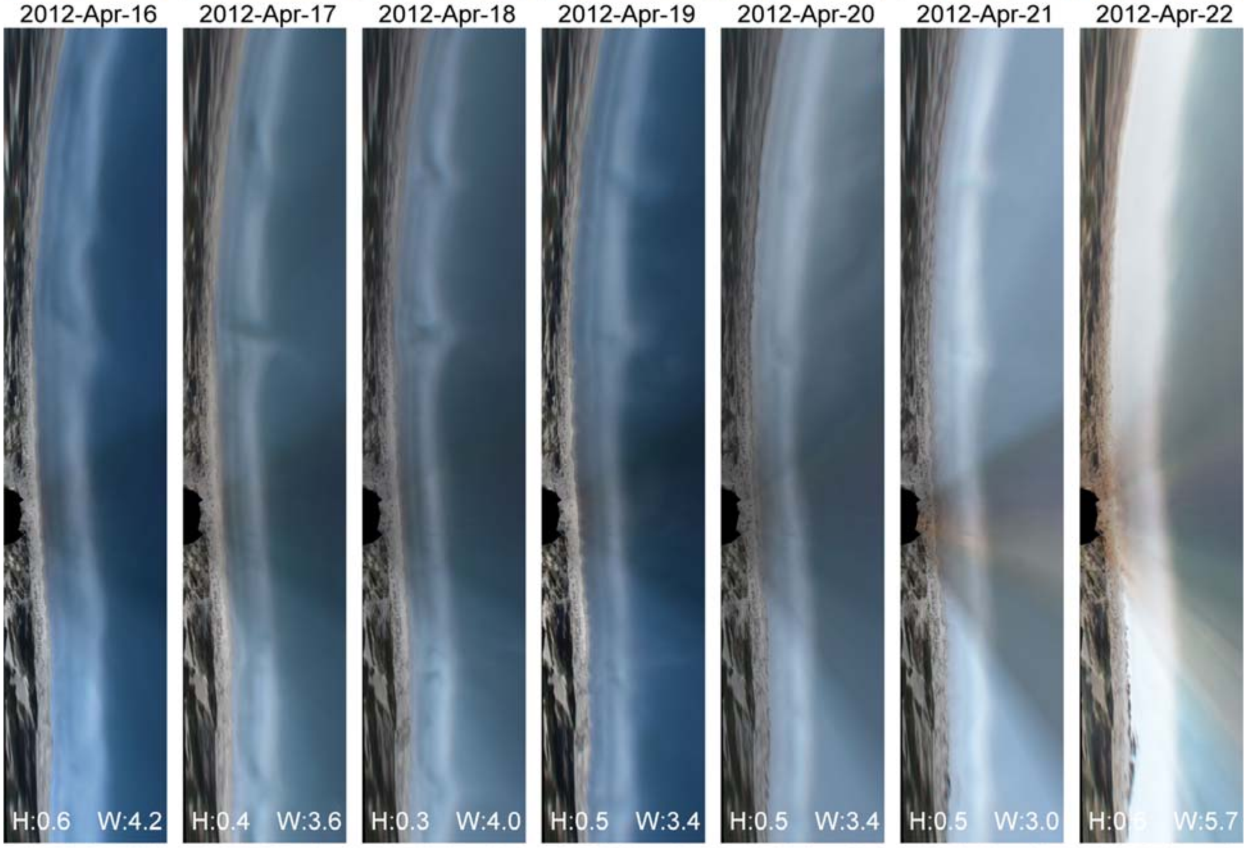

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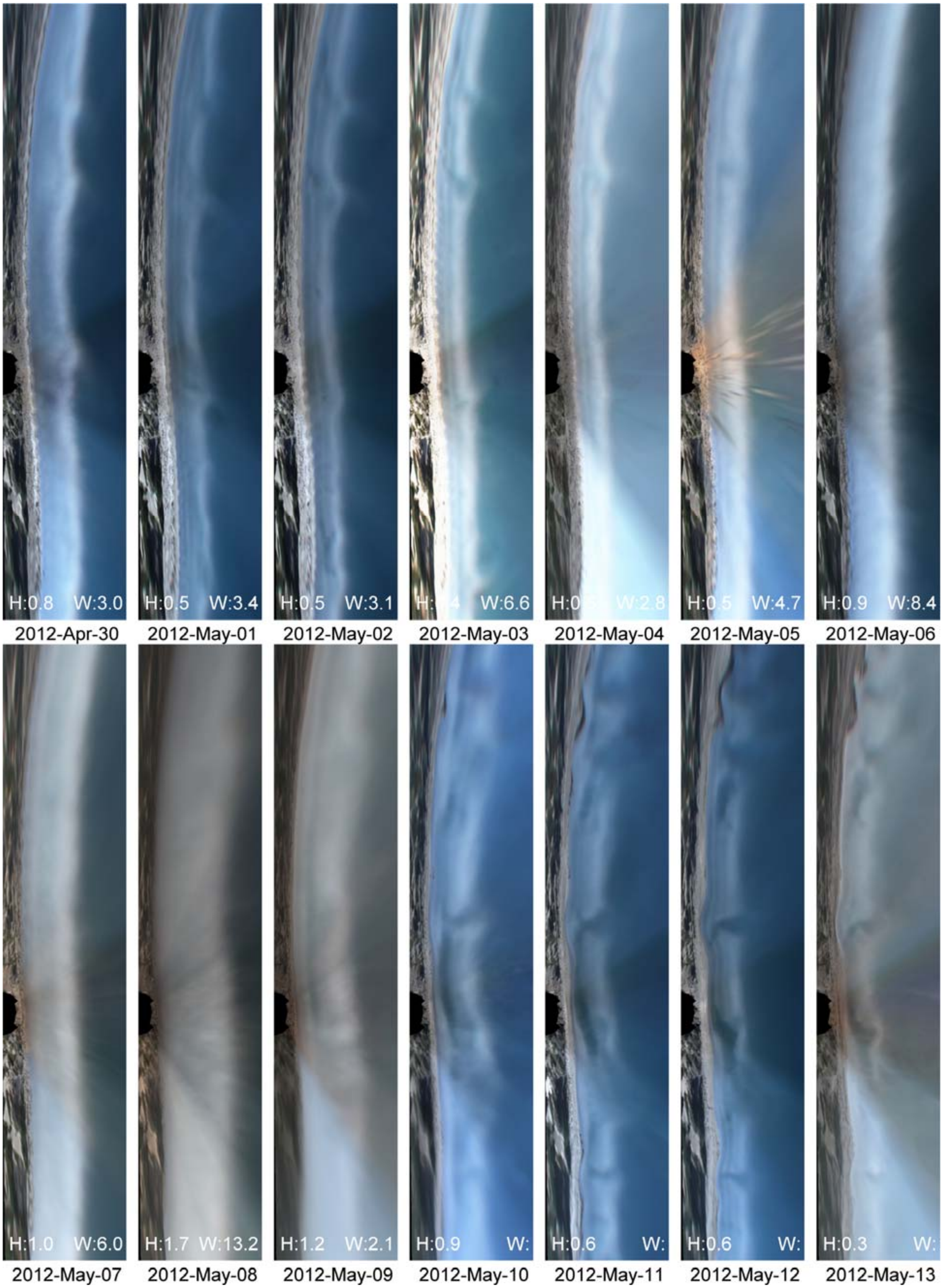
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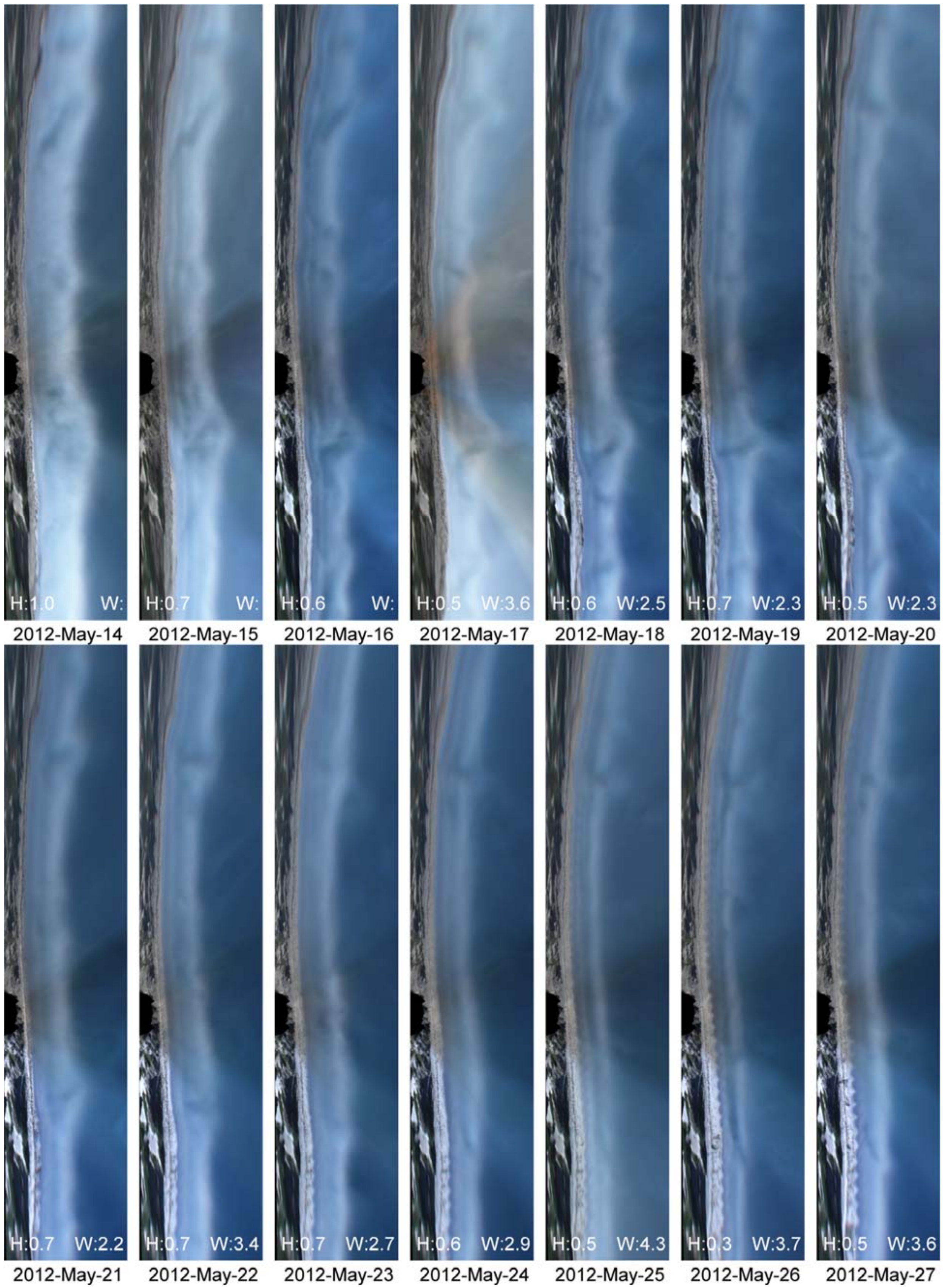
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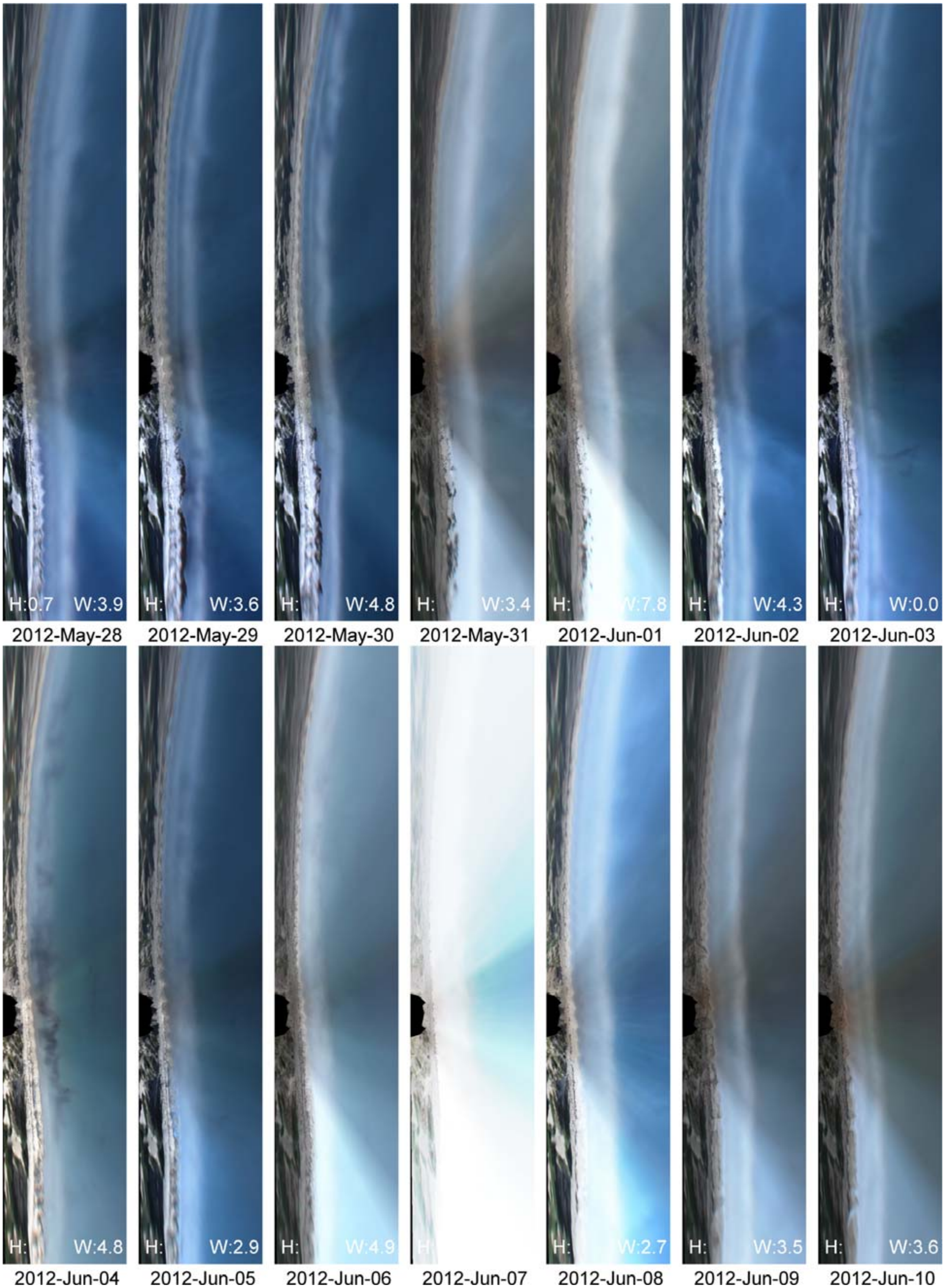
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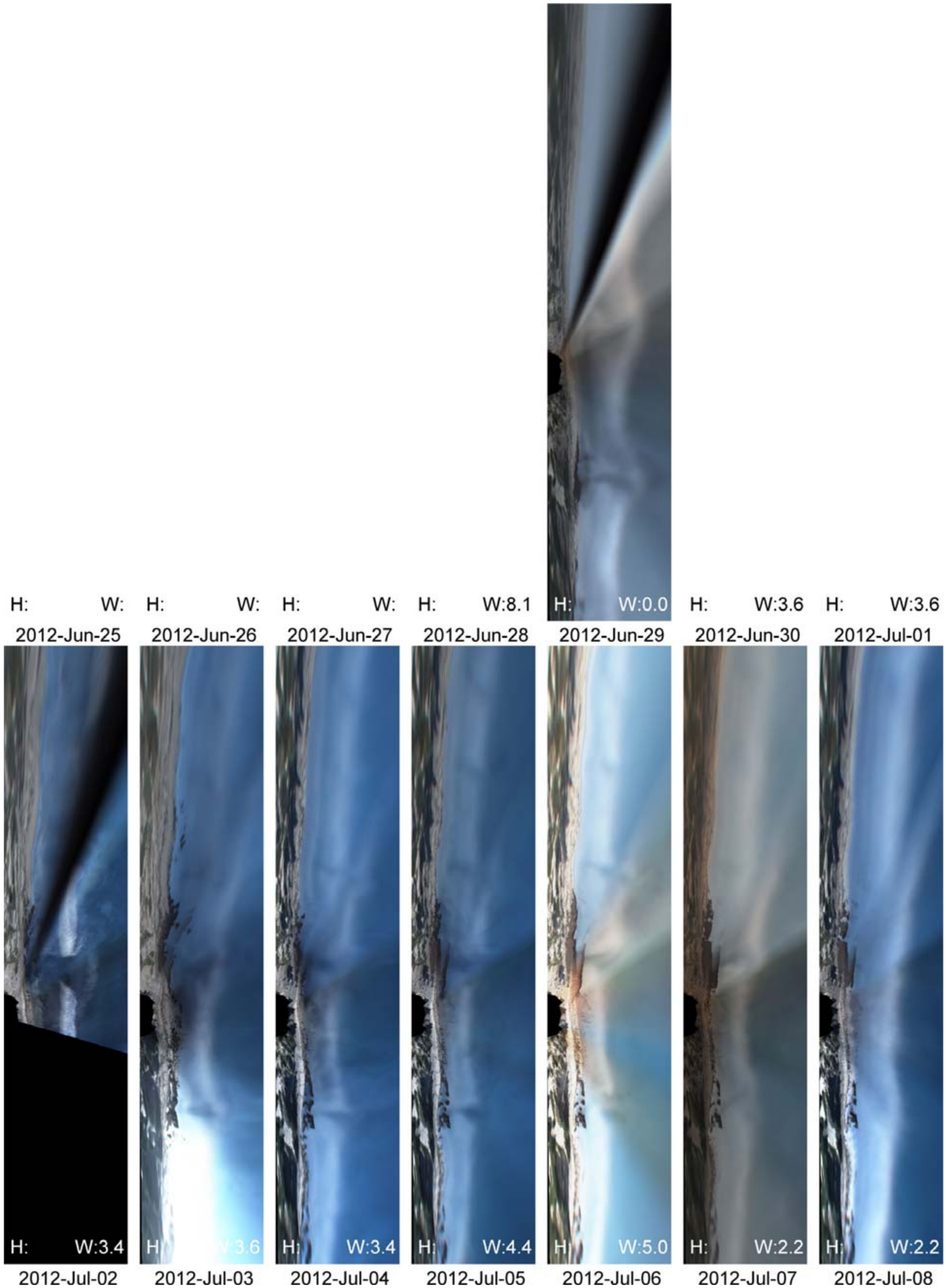
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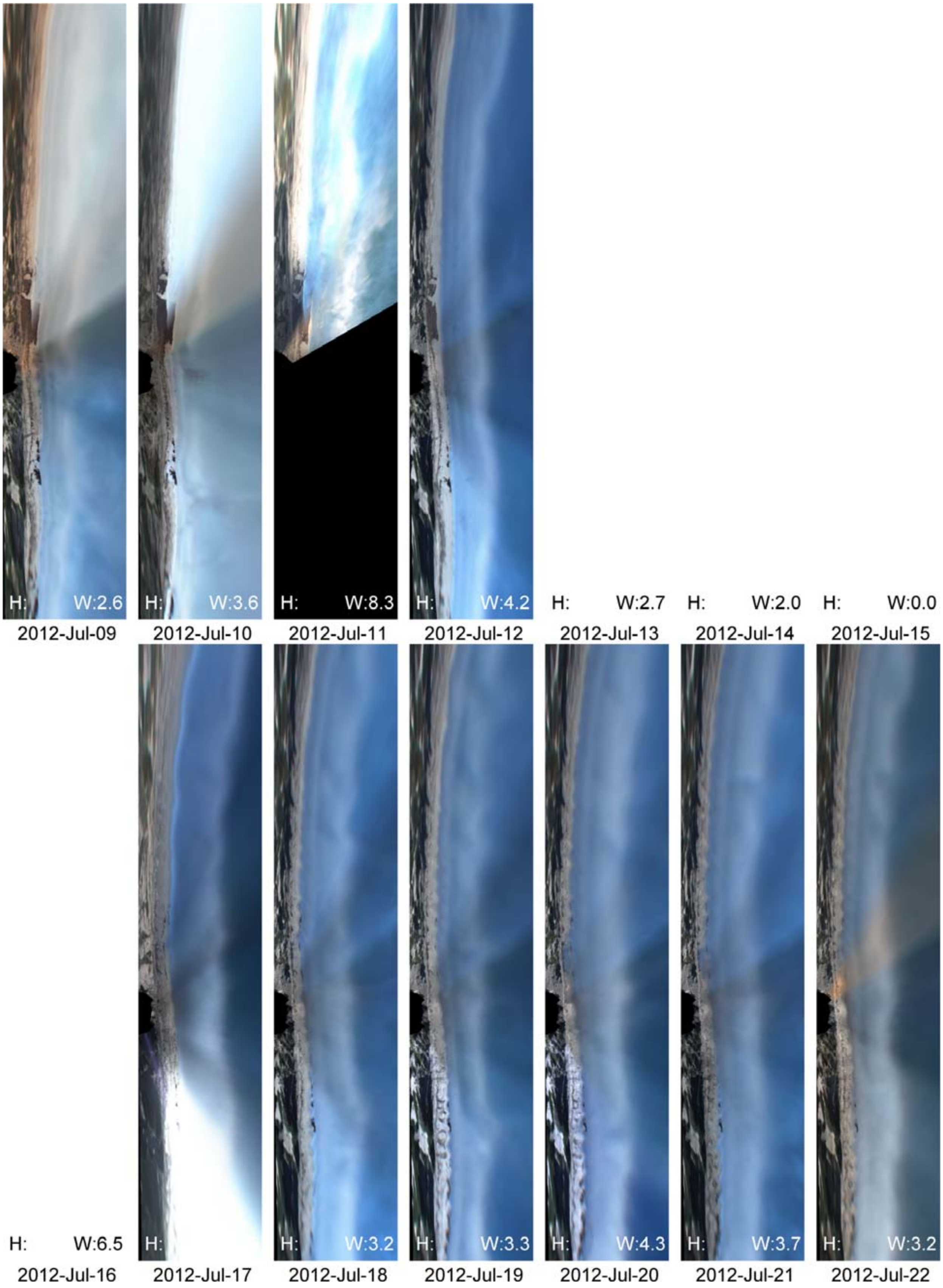
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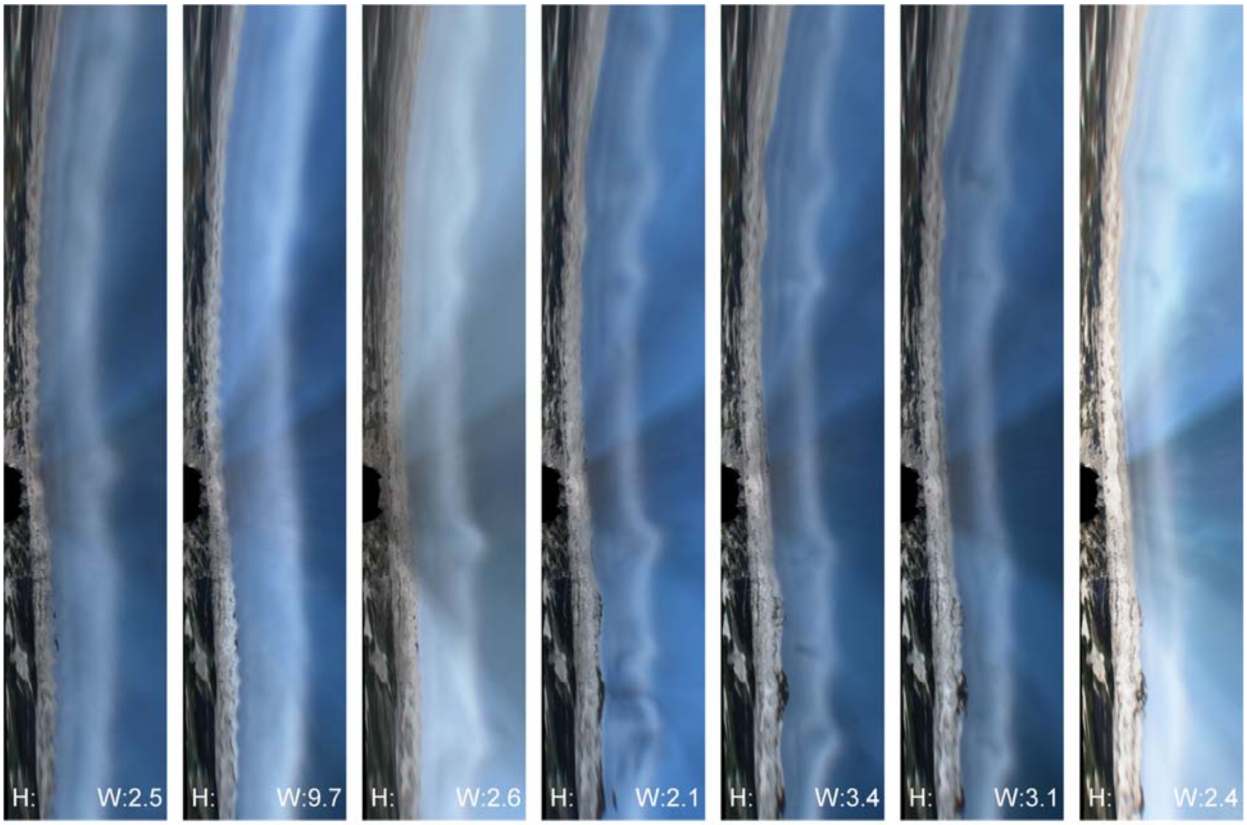

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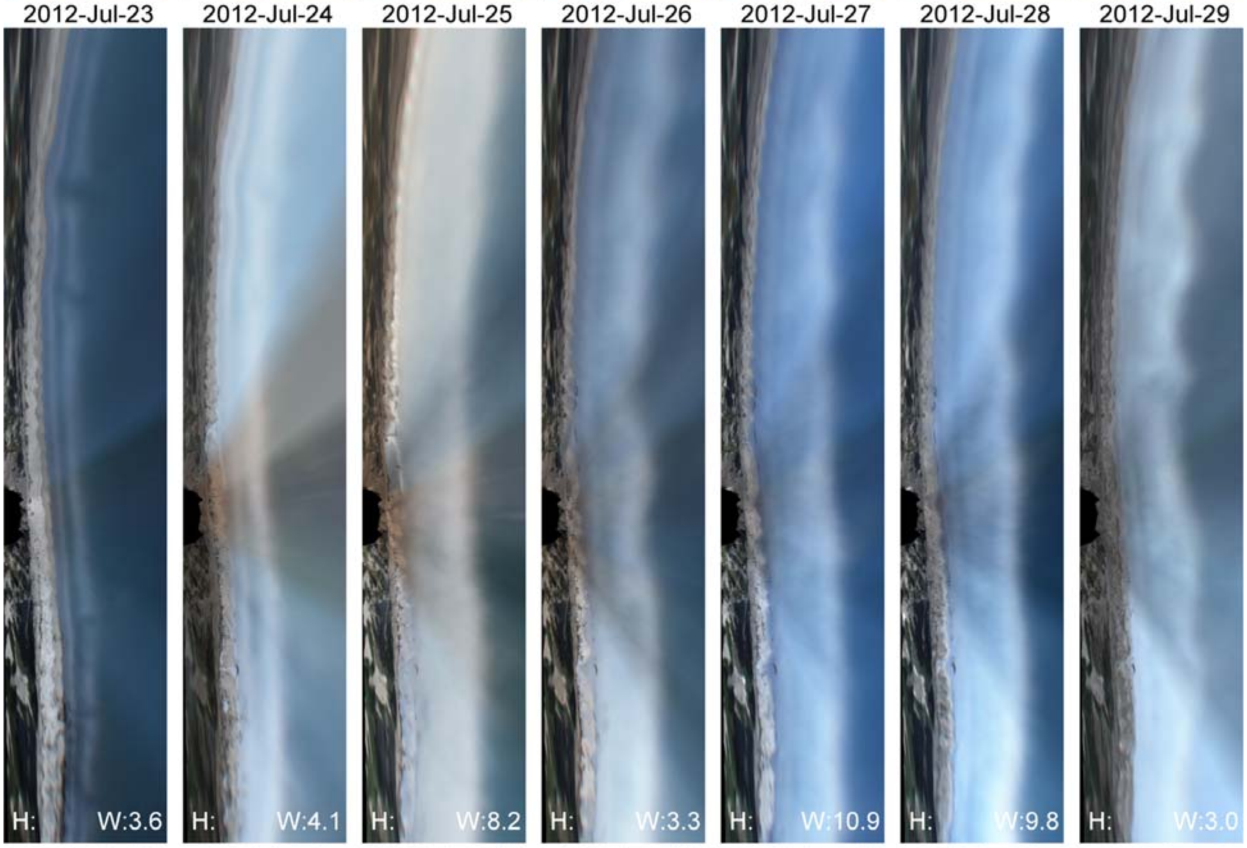

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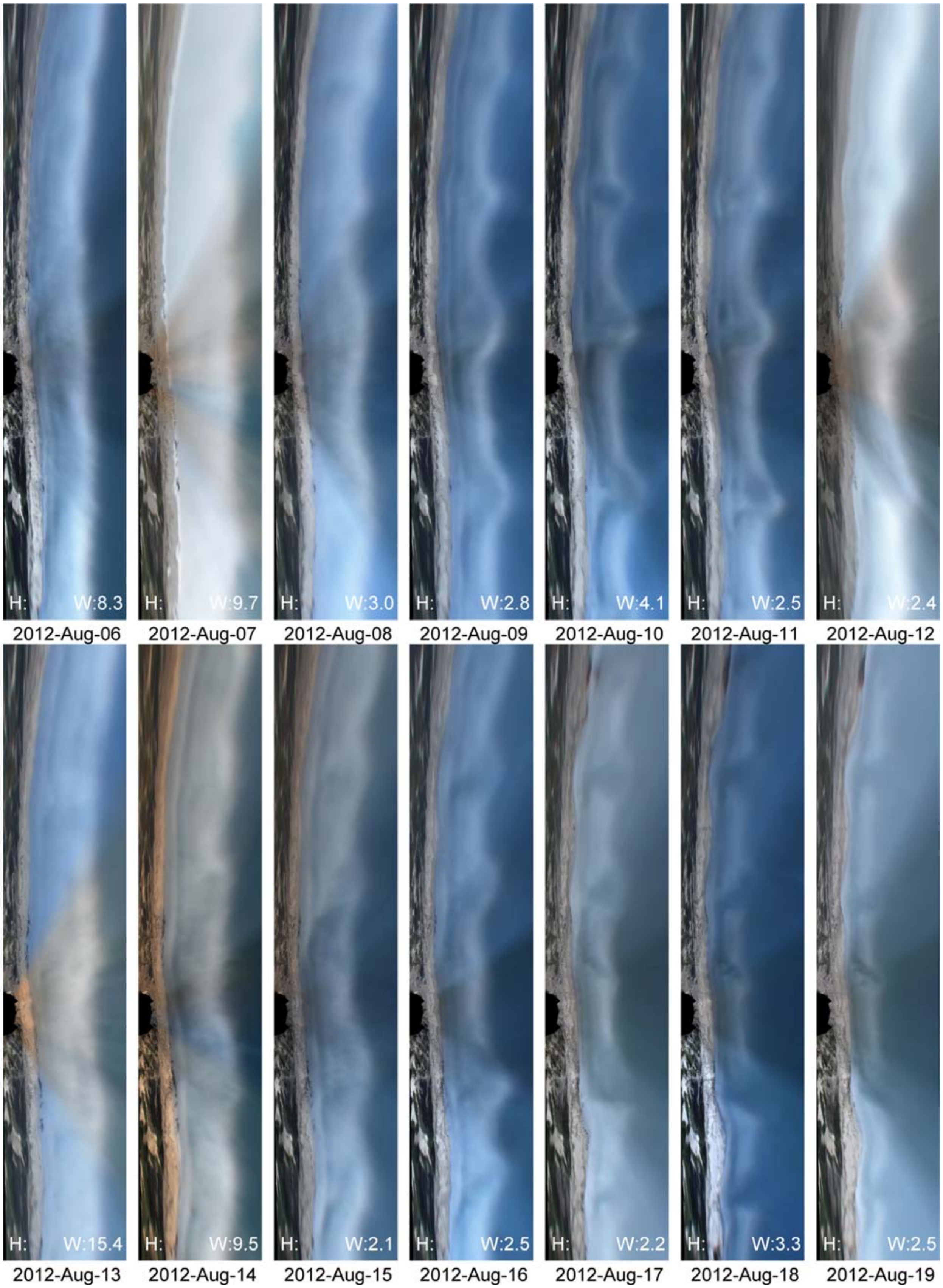
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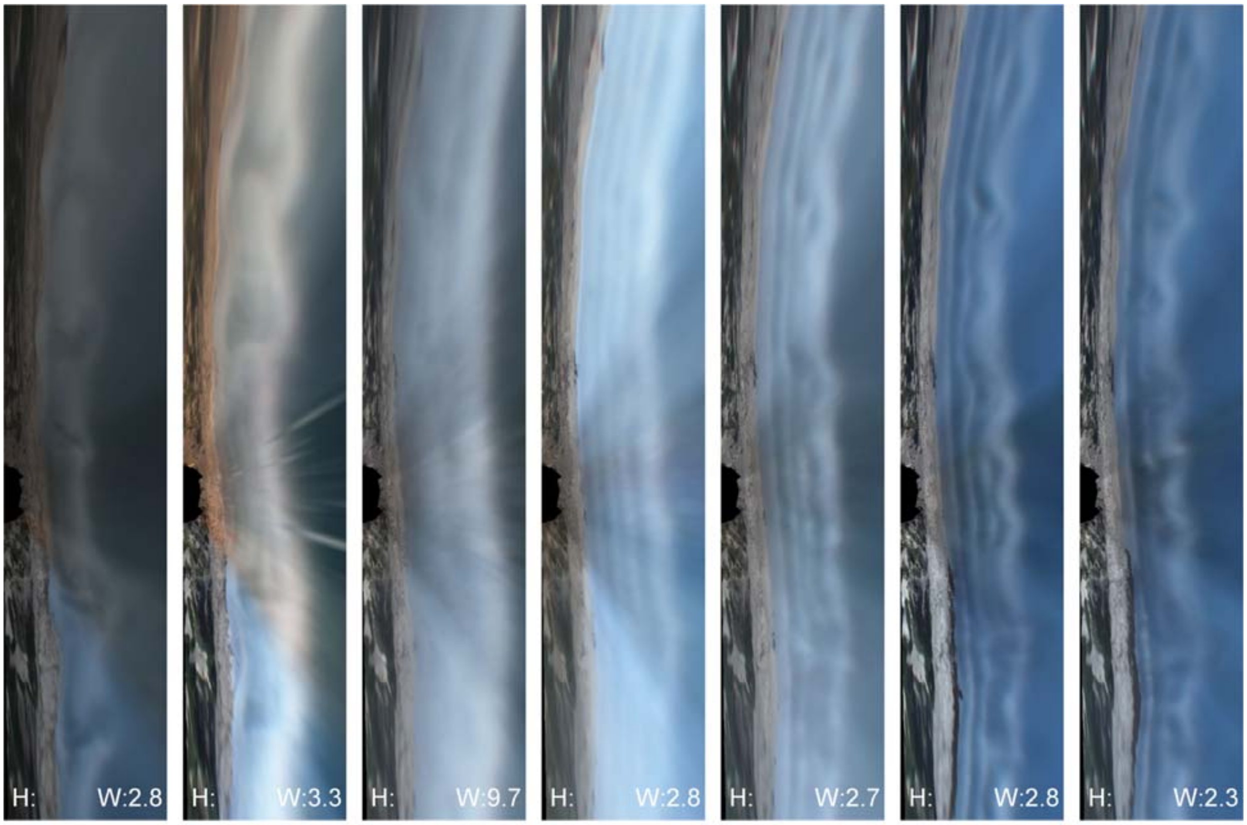

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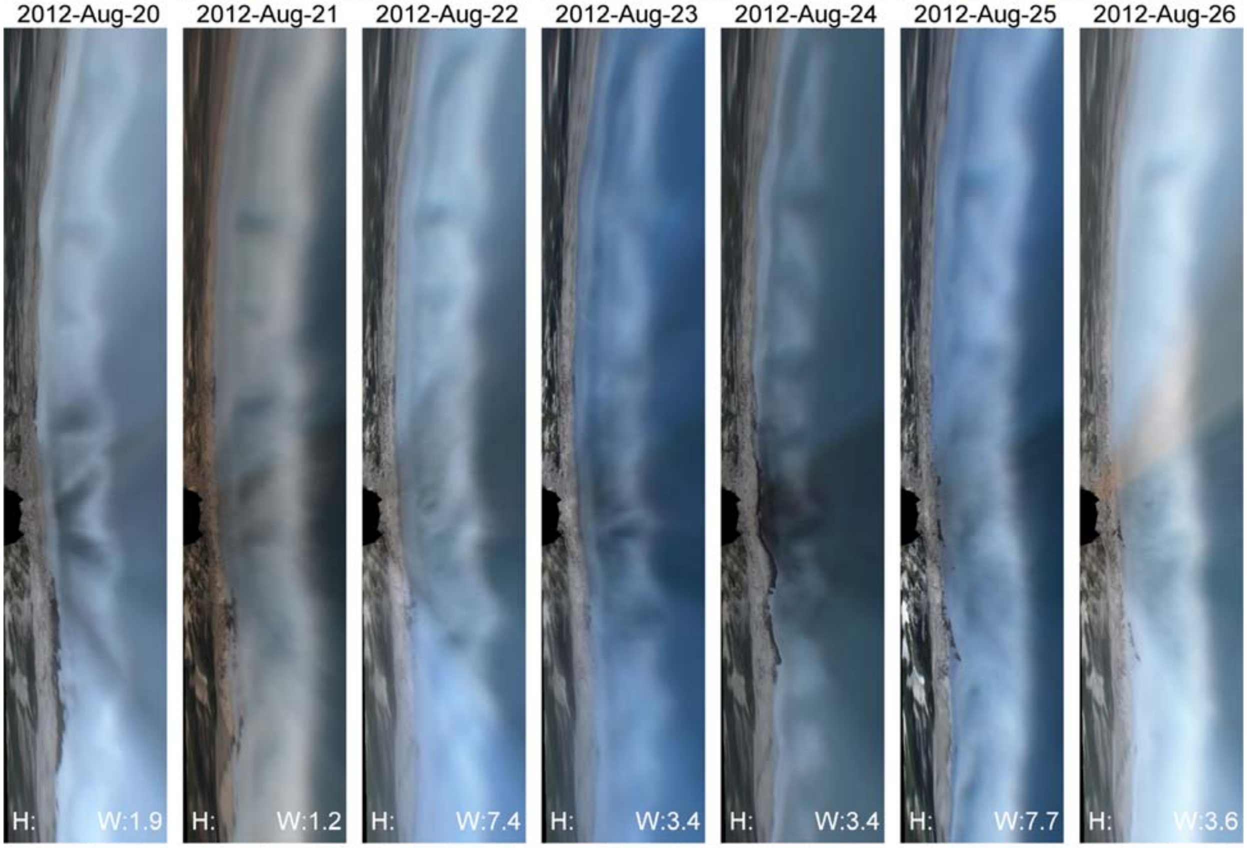

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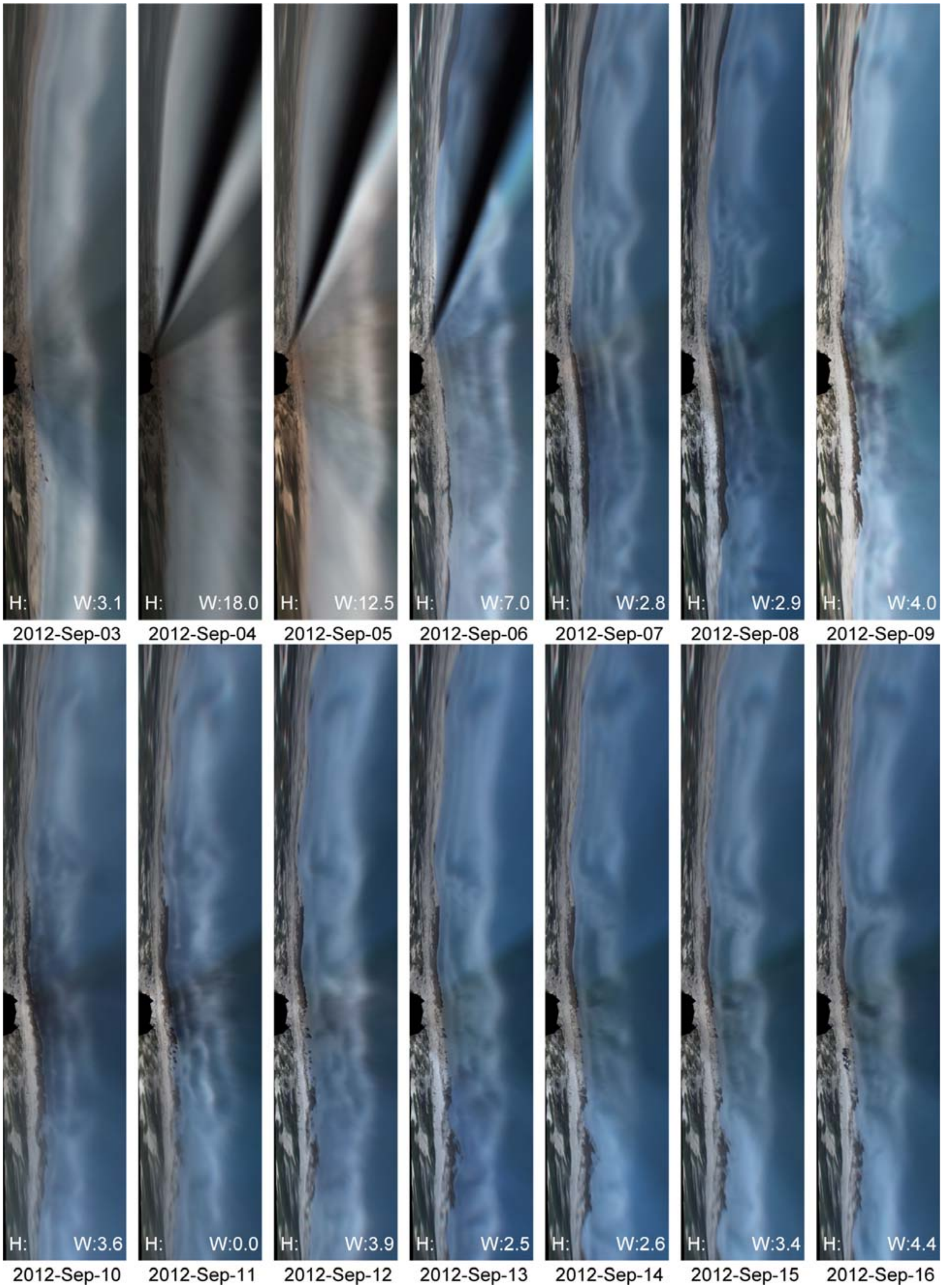
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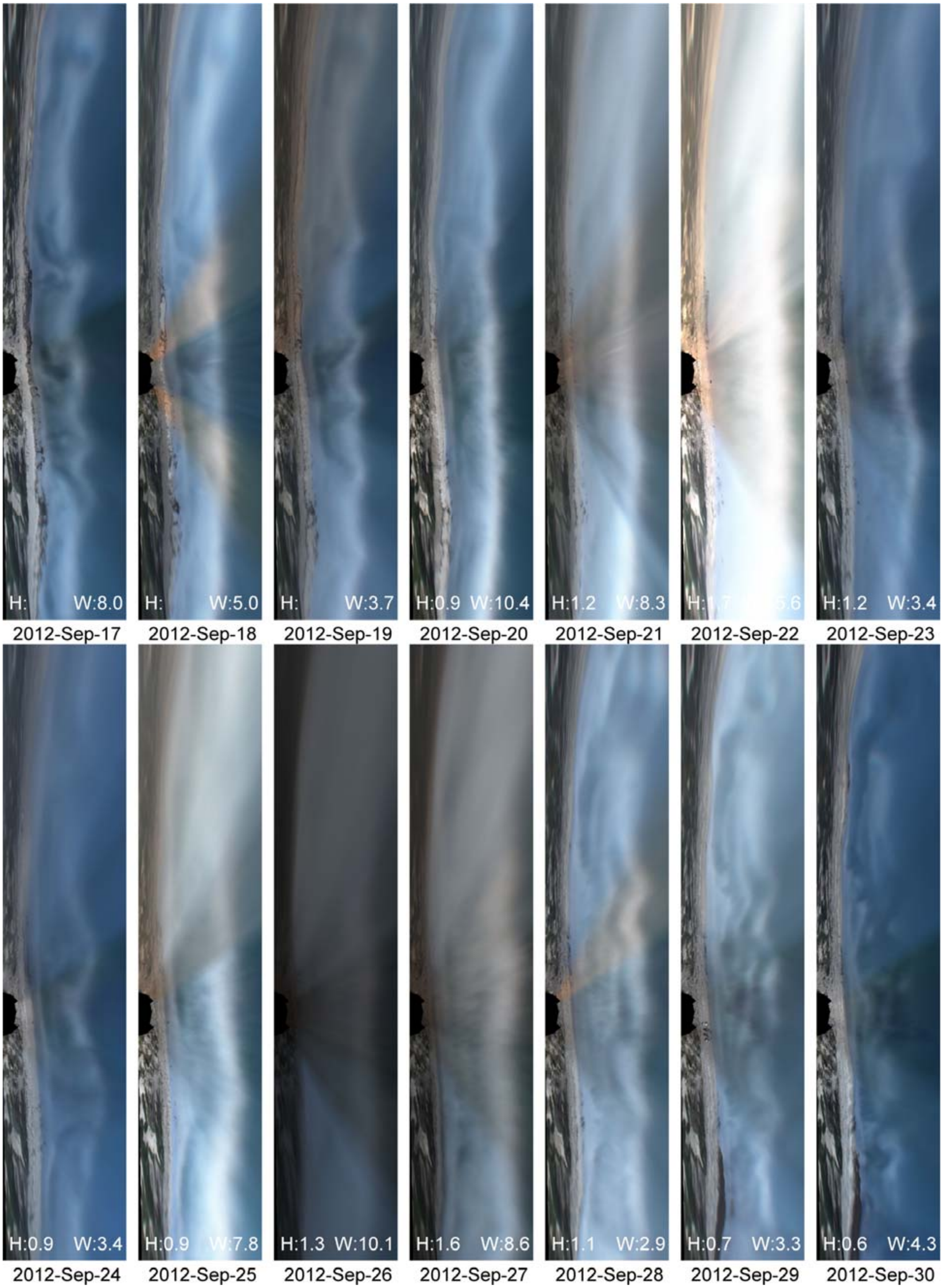
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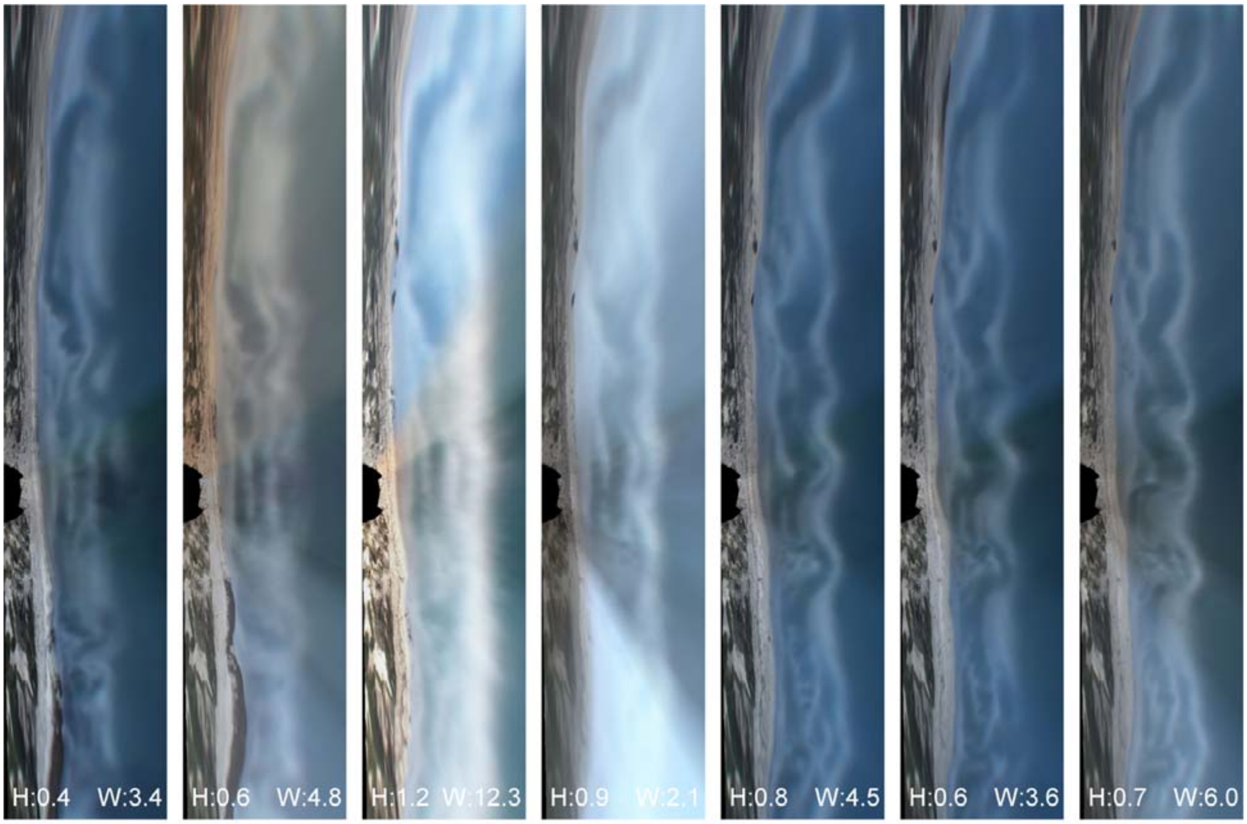

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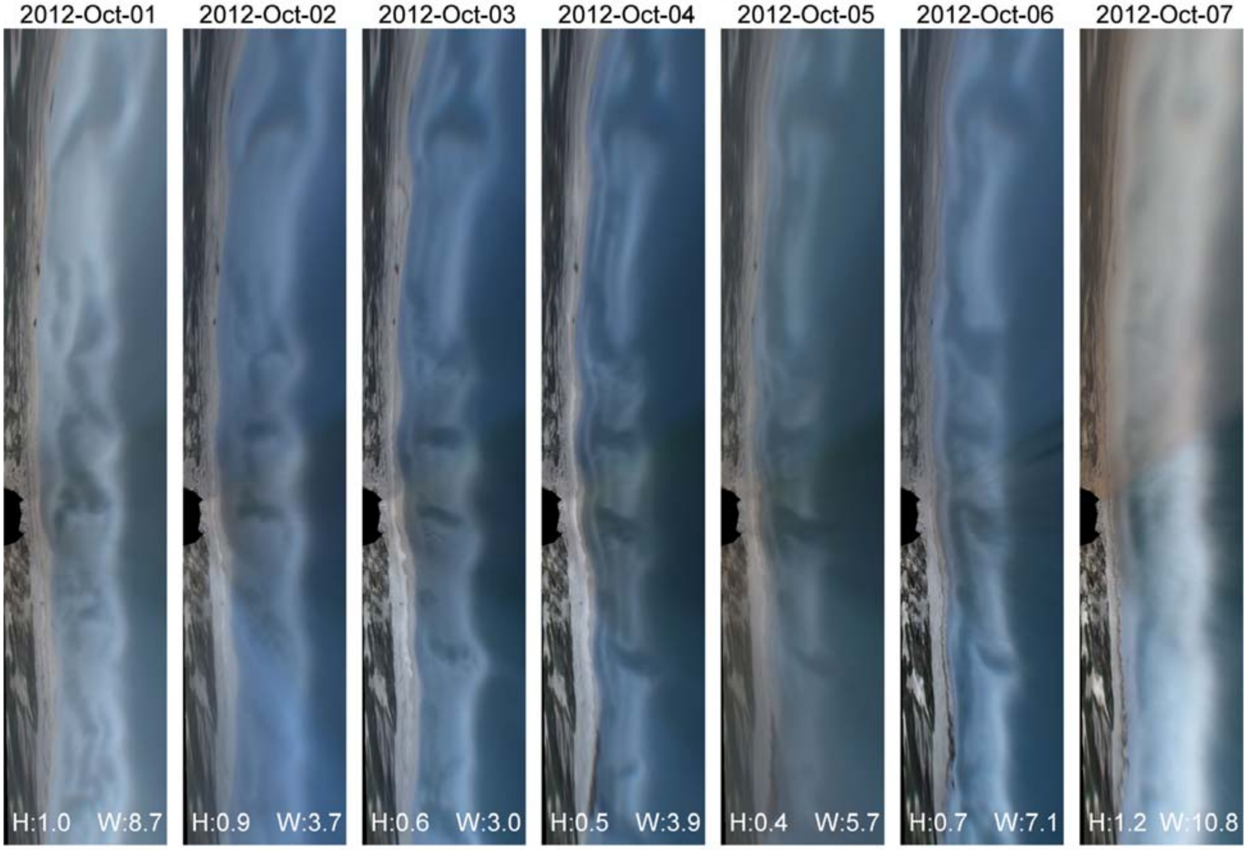

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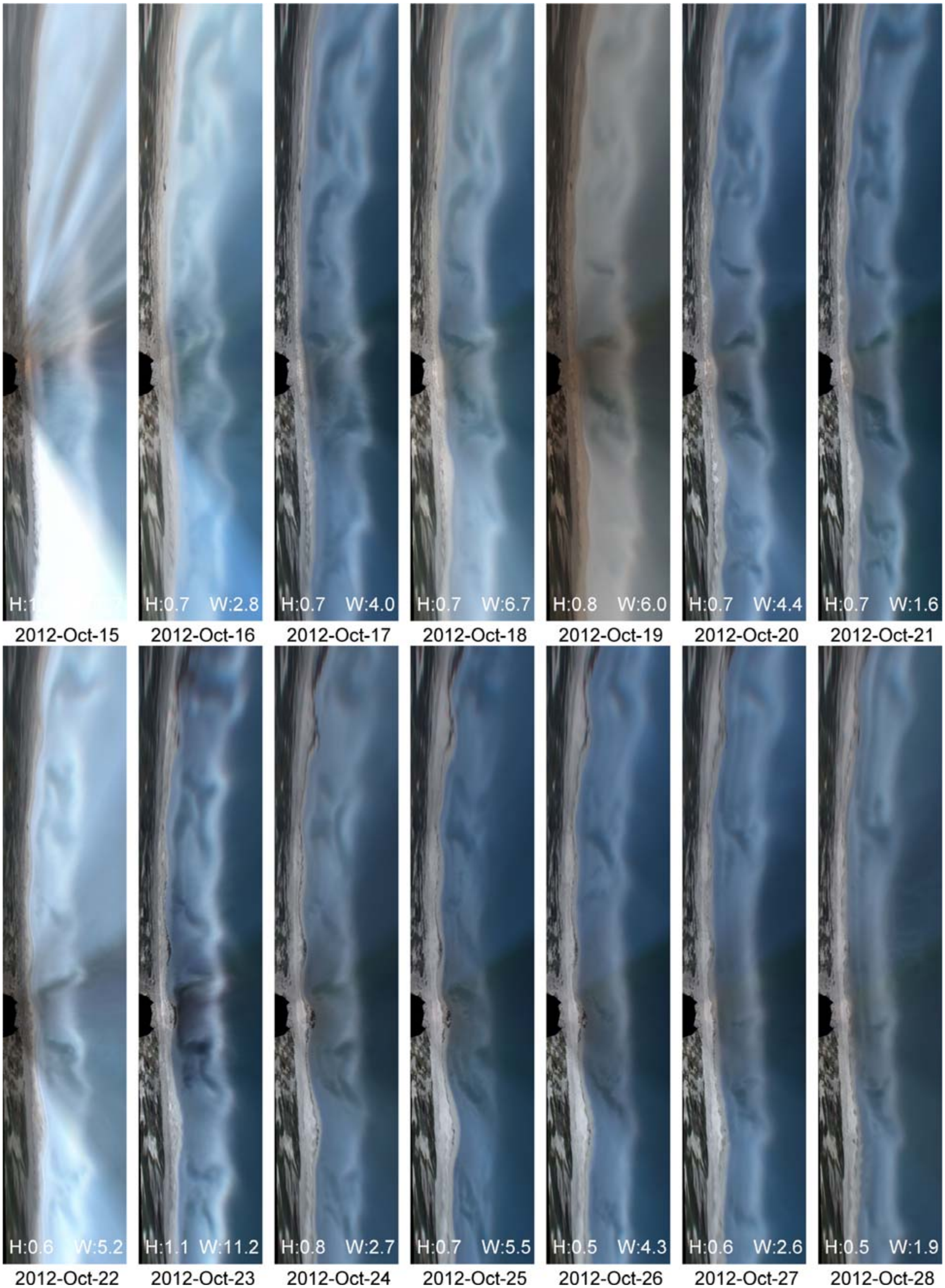
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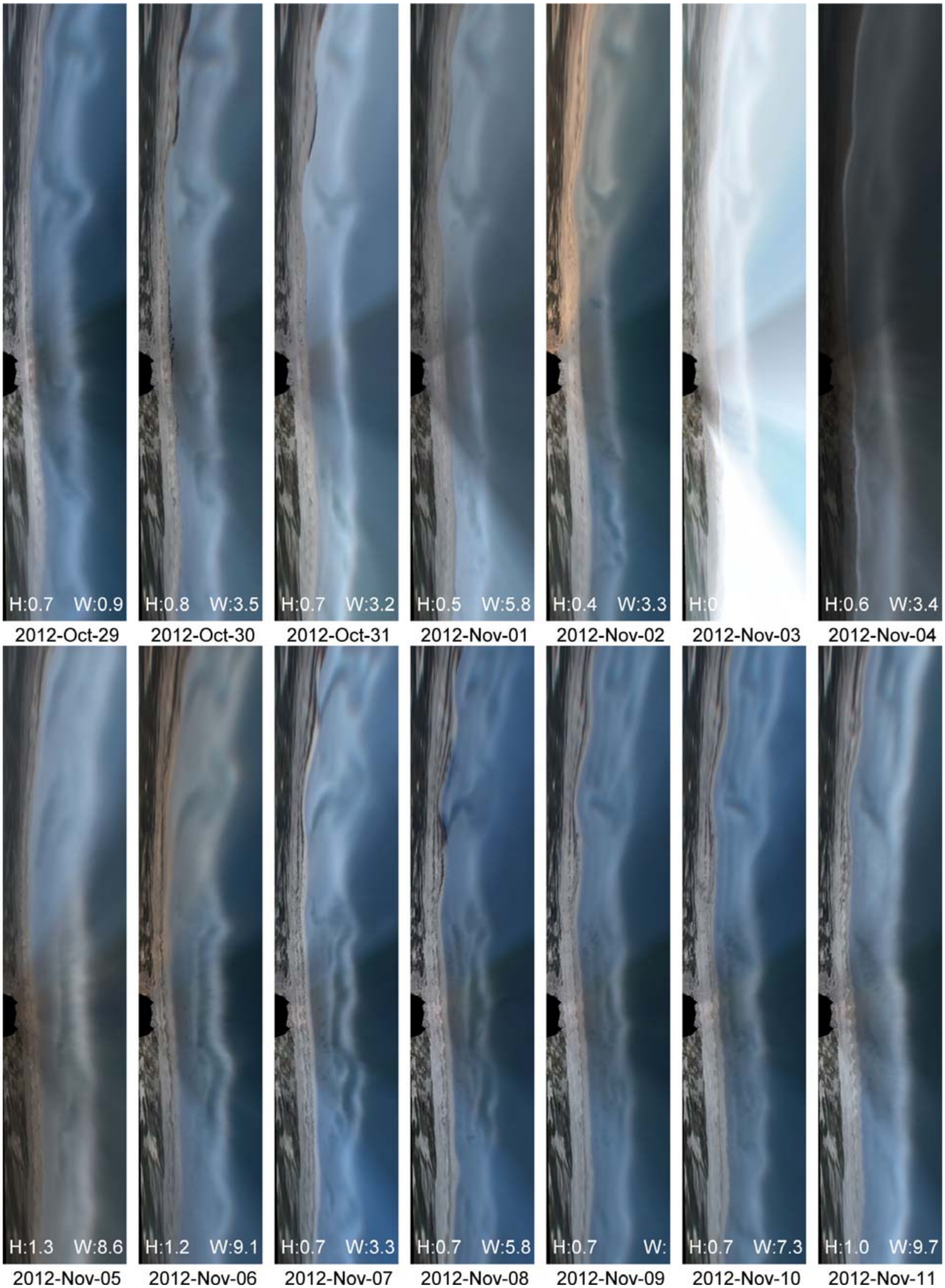
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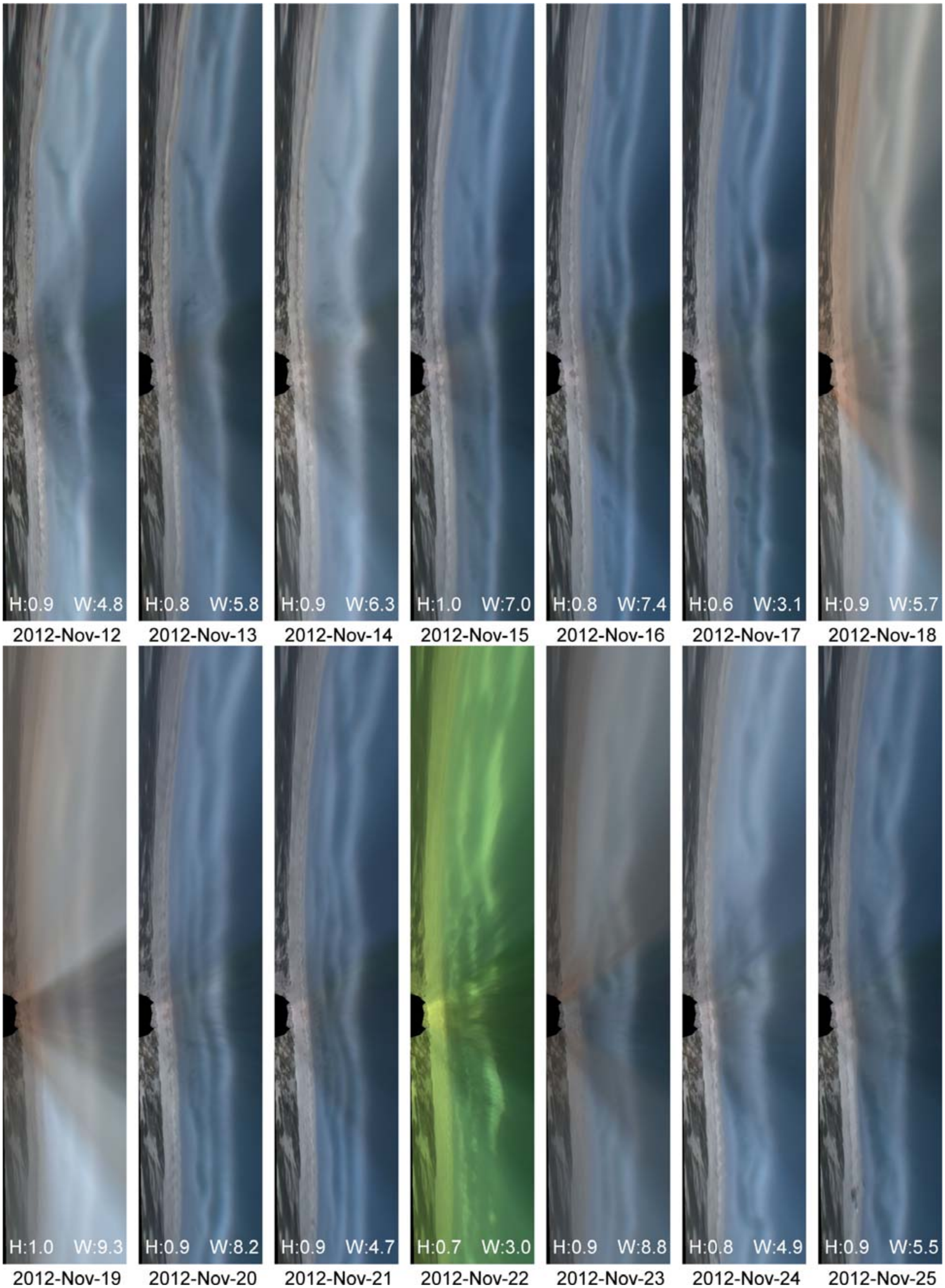
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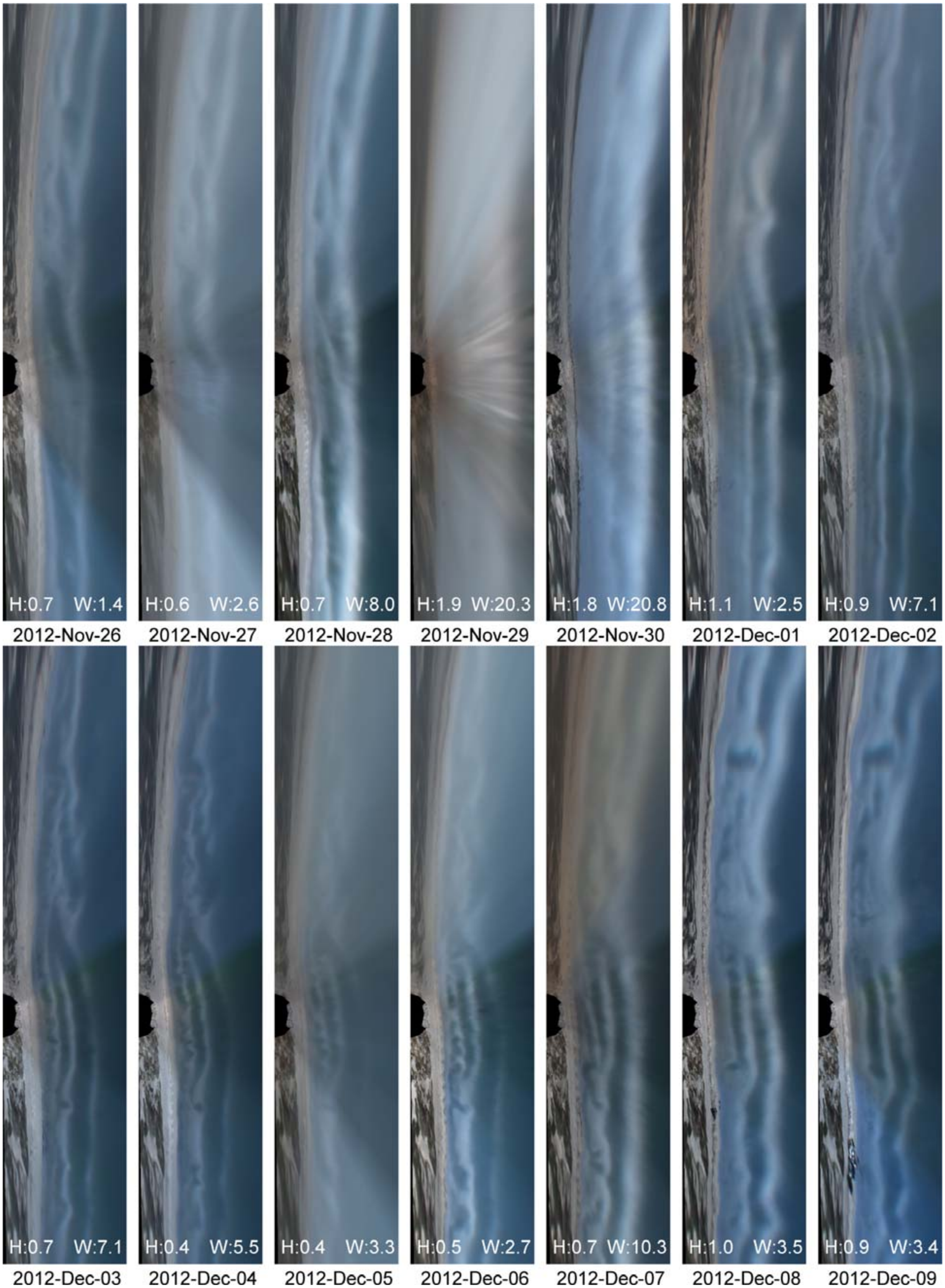
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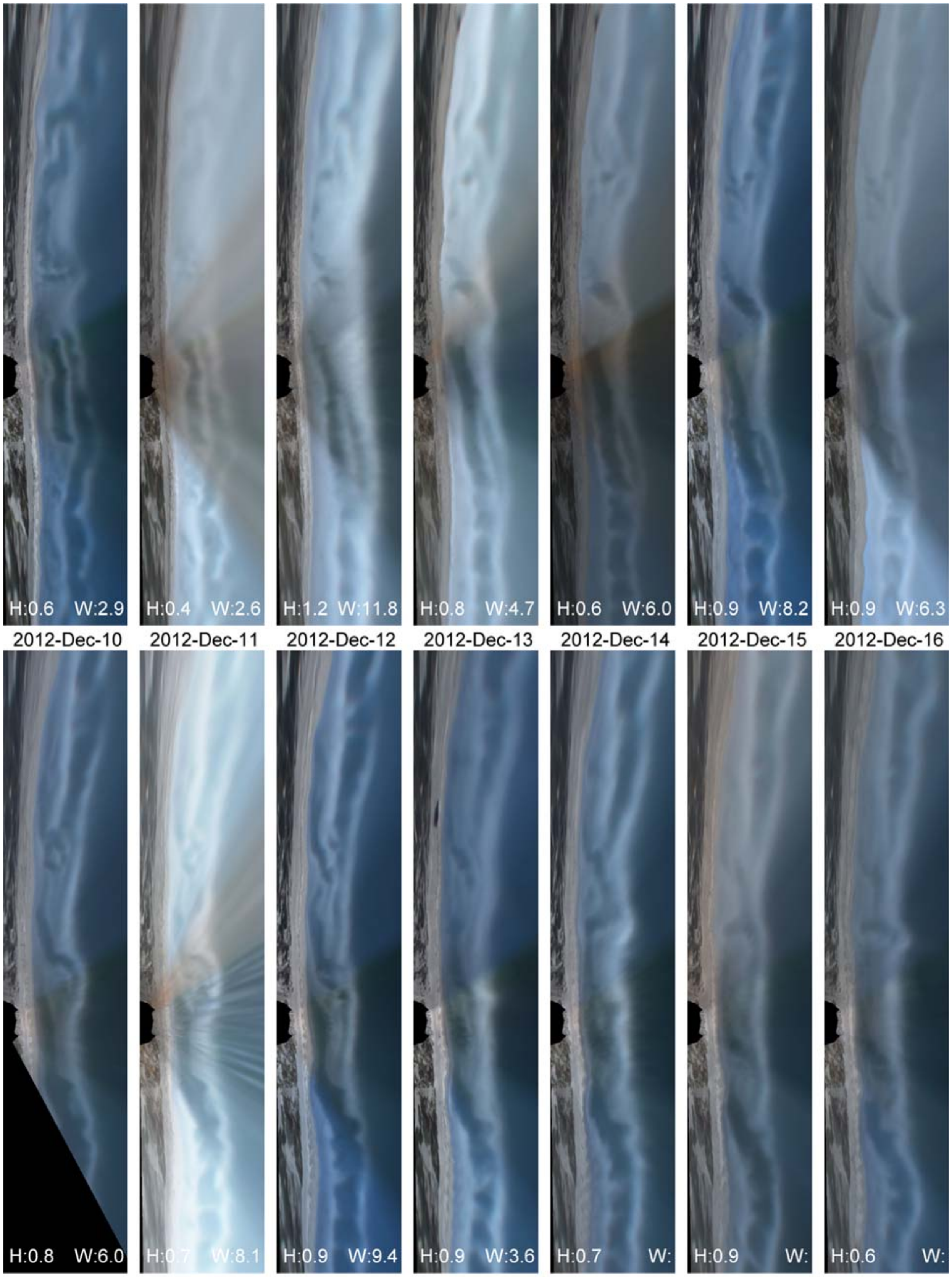

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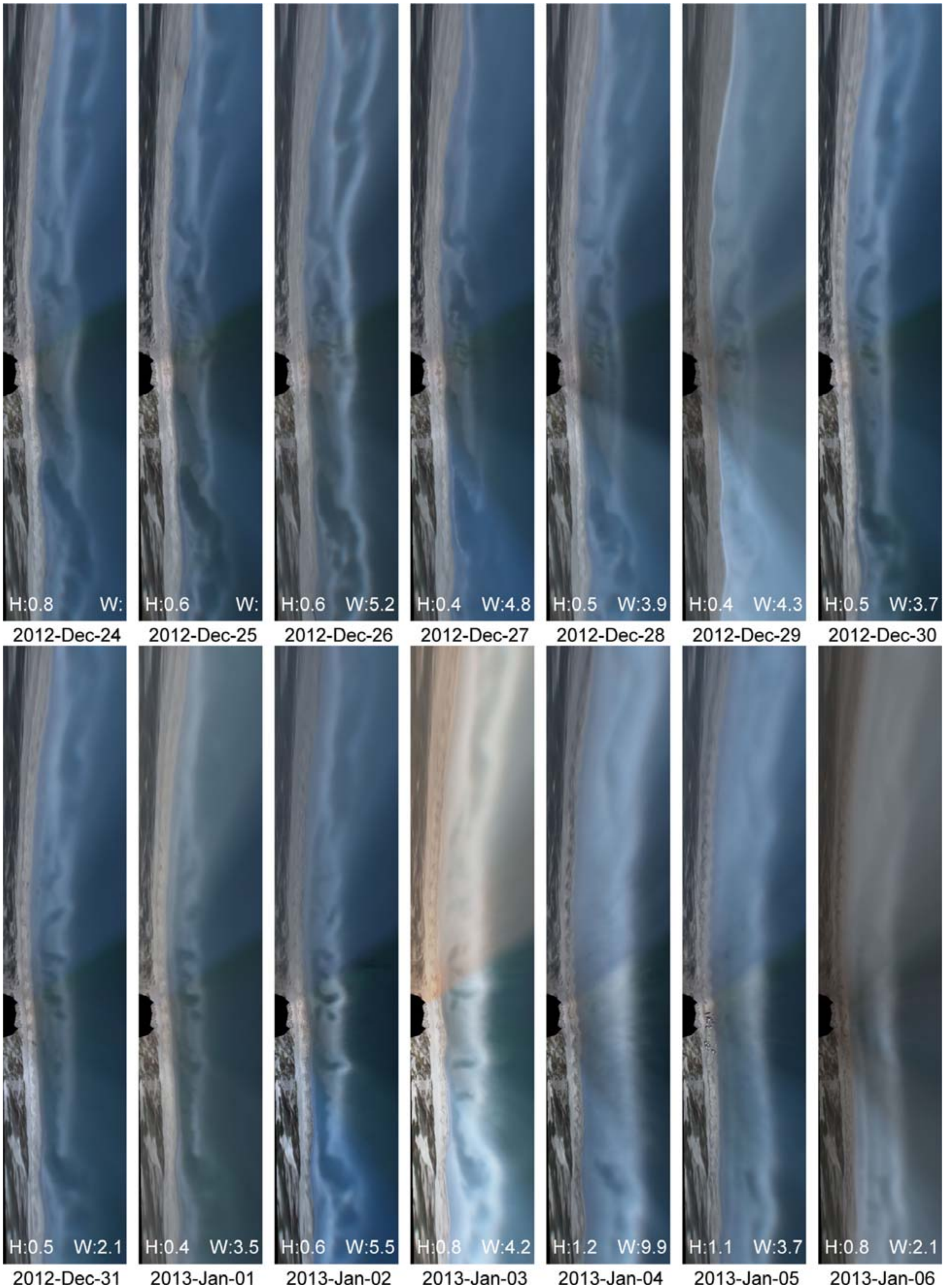
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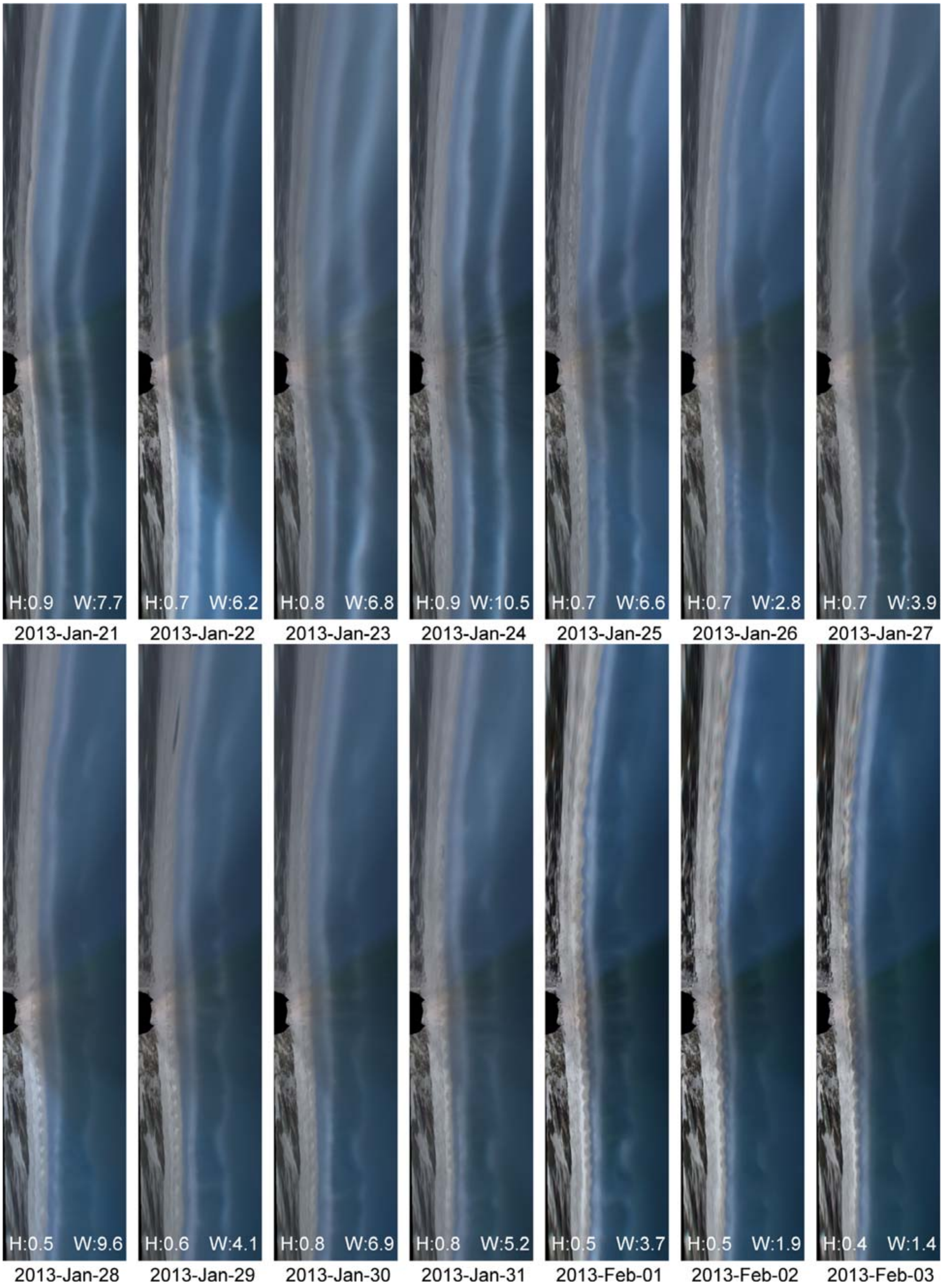
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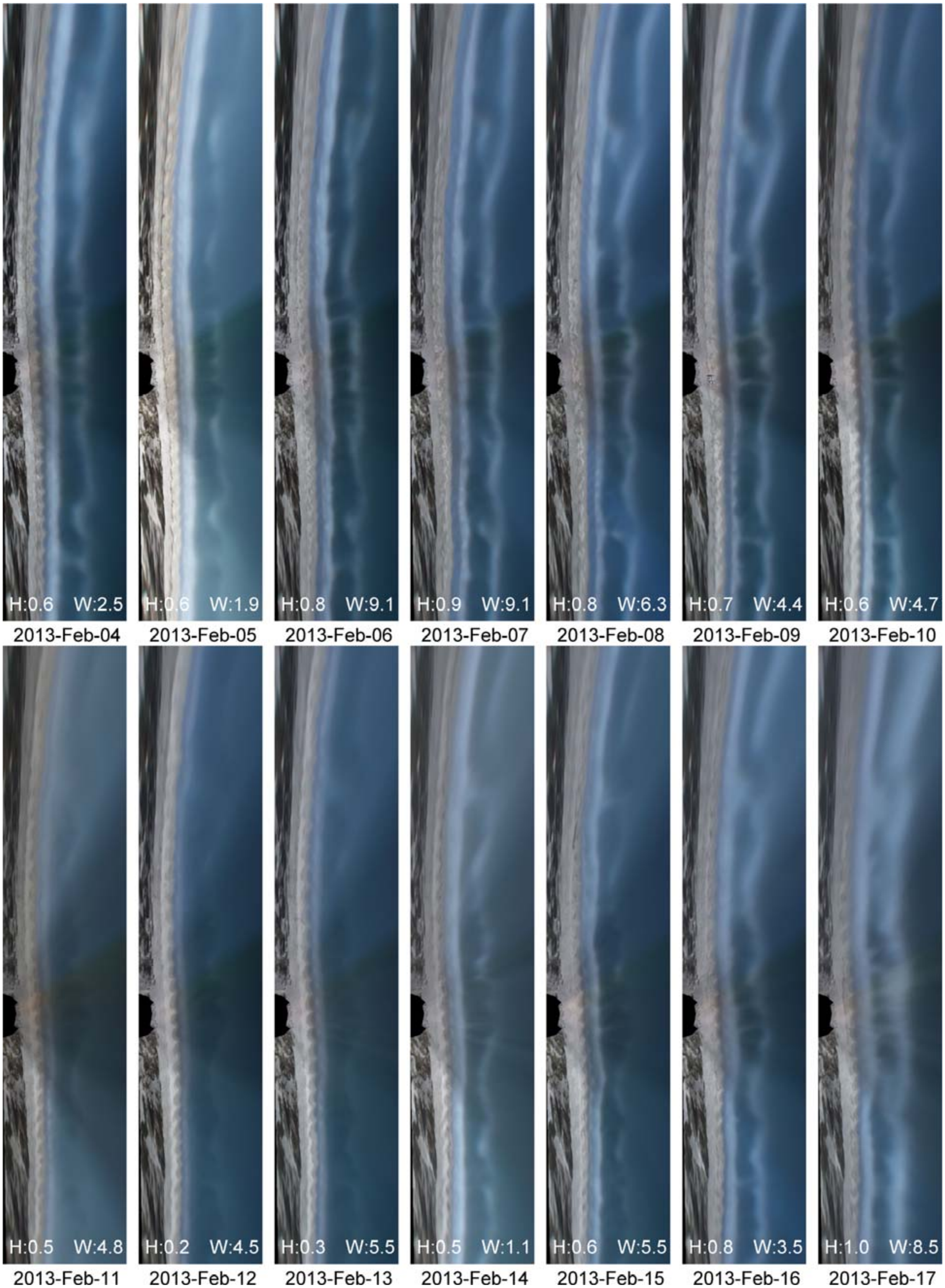
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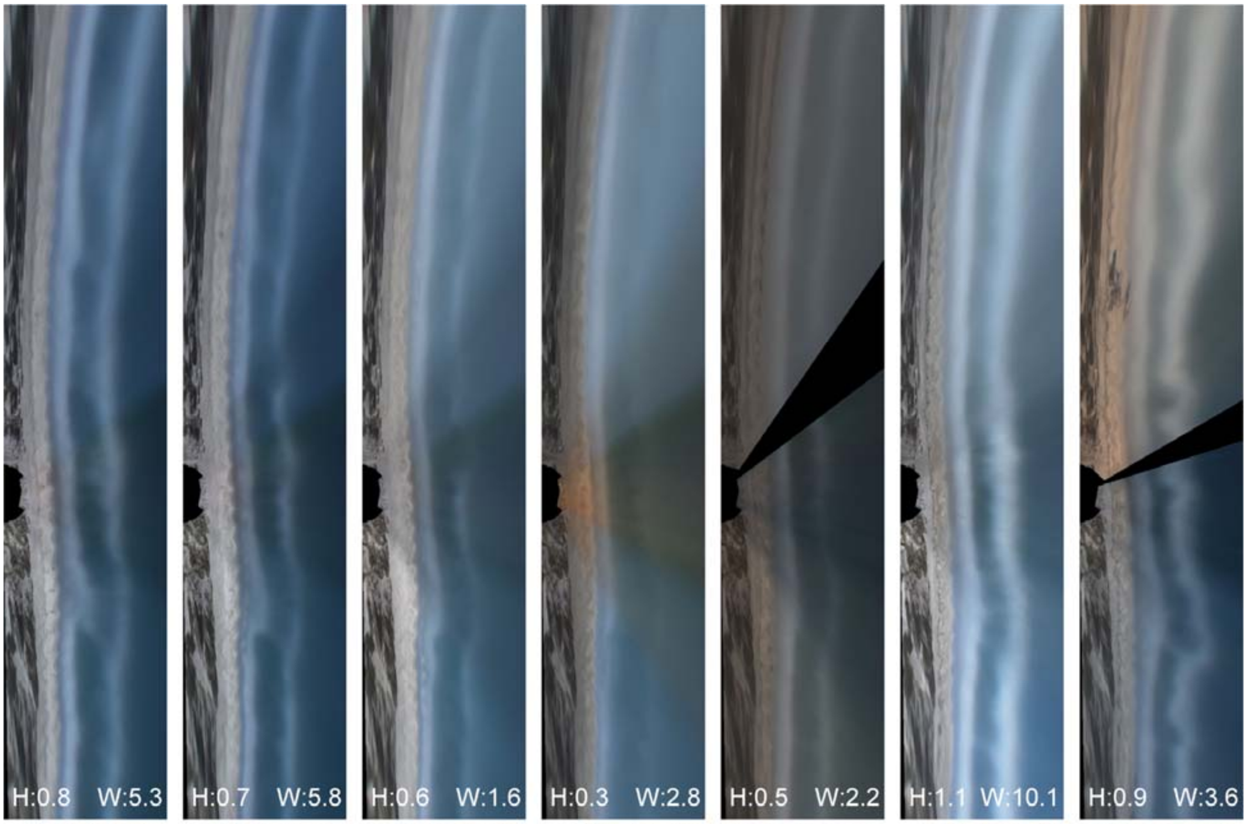

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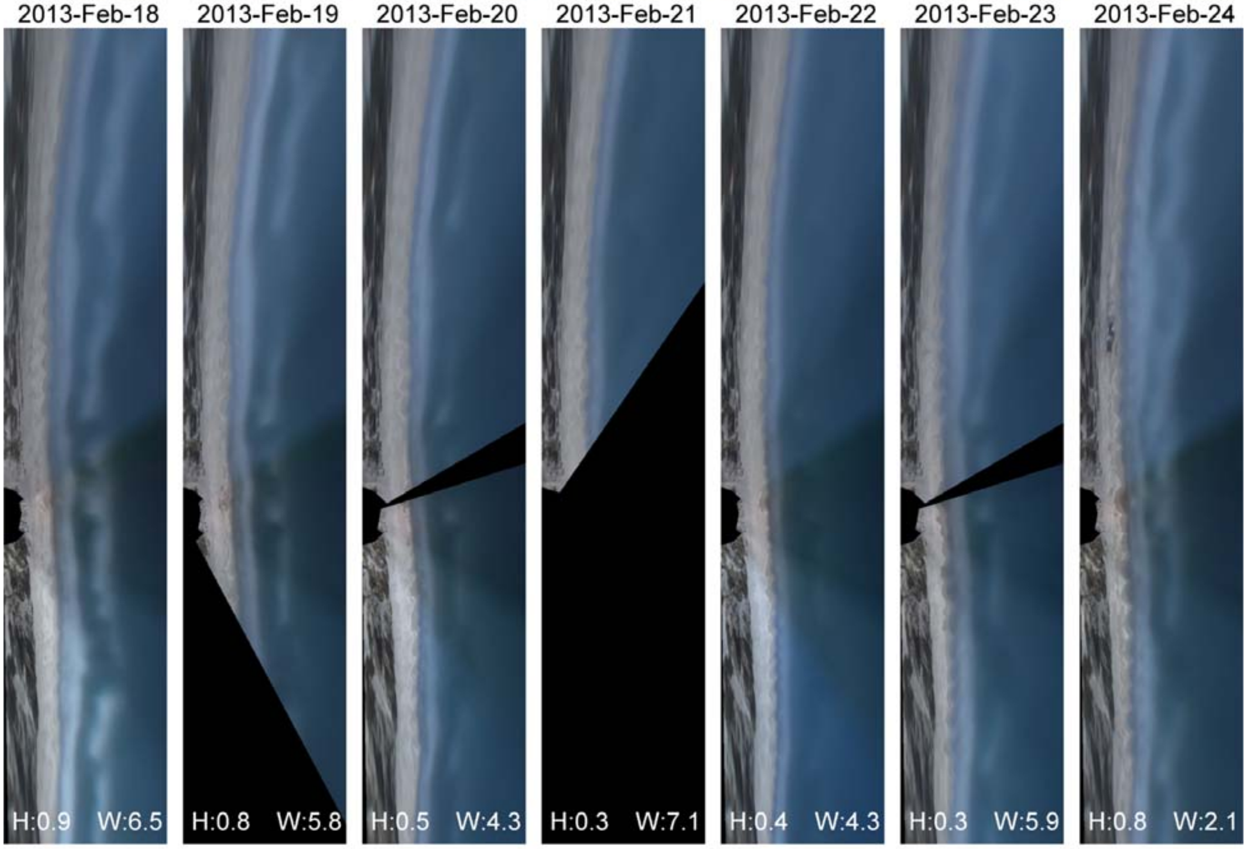

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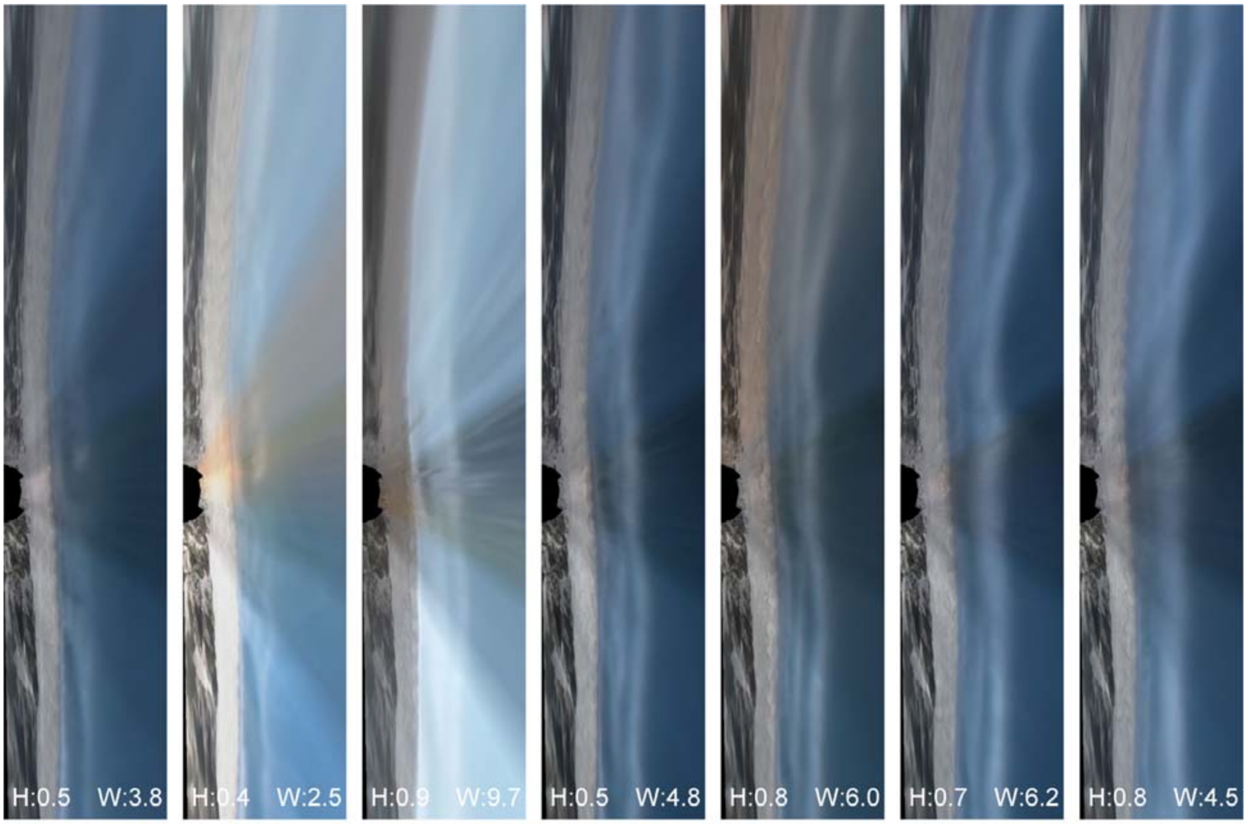

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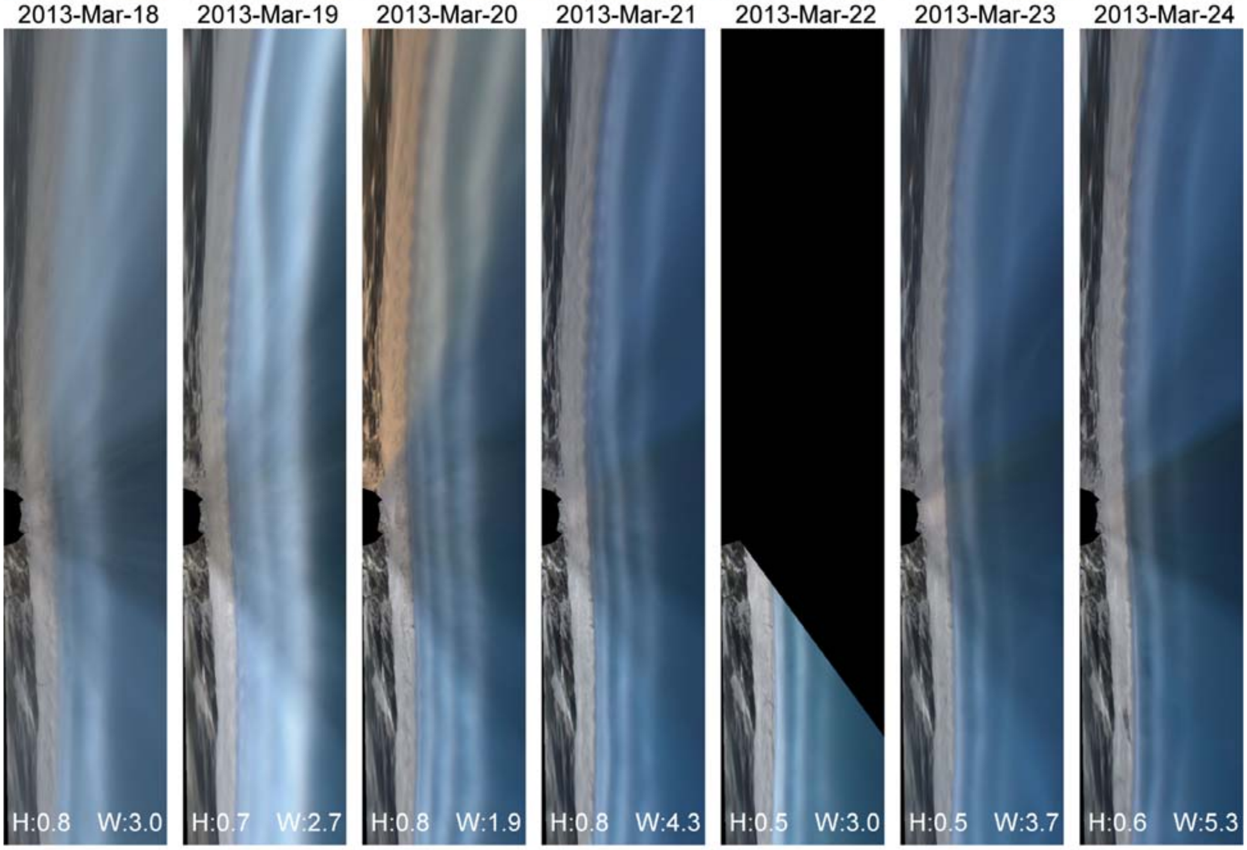

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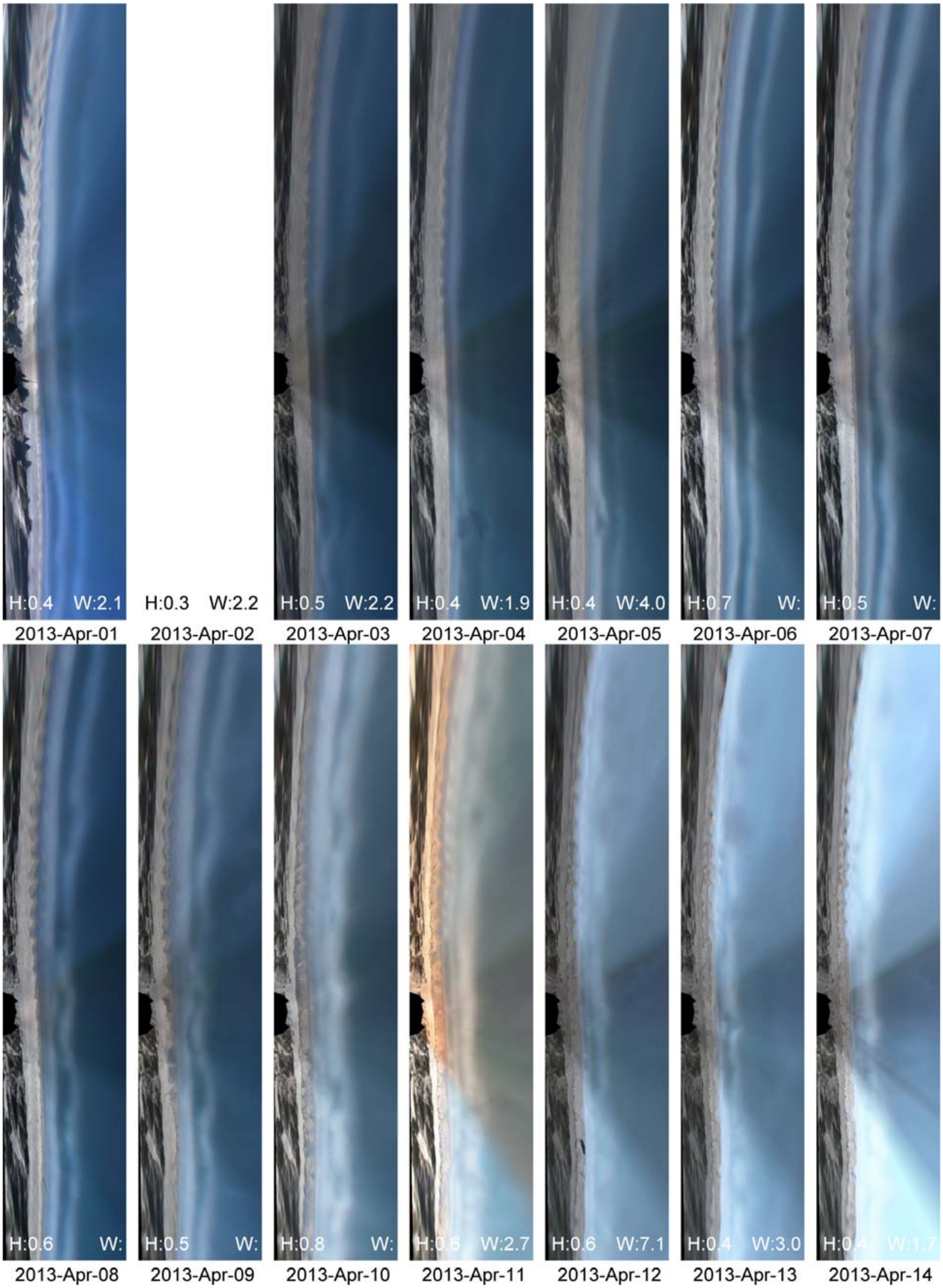
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2013-Apr-03
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2013-Apr-04
H:0.4 W:4.0
2013-Apr-05
H:0.7 W:
2013-Apr-06
H:0.5 W:
2013-Apr-07
H:0.6 W:
2013-Apr-08
H:0.5 W:
2013-Apr-09
H:0.8 W:
2013-Apr-10
H:0.6 W:2.7
2013-Apr-11
H:0.6 W:7.1
2013-Apr-12
H:0.4 W:3.0
2013-Apr-13
H:0.4 W:1.7
2013-Apr-14

2013-Apr-15

2013-Apr-16

2013-Apr-17

2013-Apr-18

2013-Apr-19

2013-Apr-20

2013-Apr-21

2013-Apr-22

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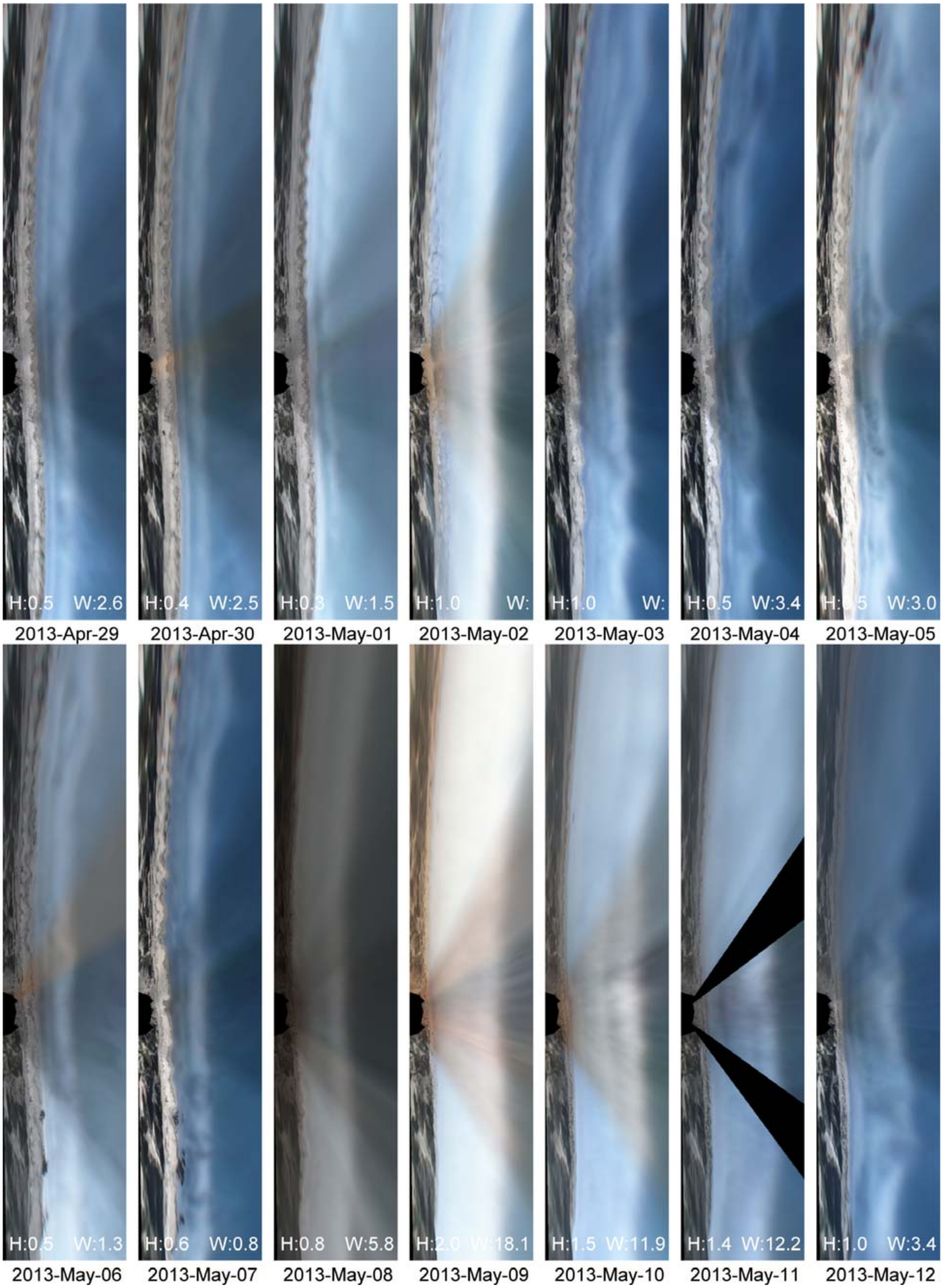
2013-Apr-25

2013-Apr-26

2013-Apr-27

2013-Apr-28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2013-Apr-30
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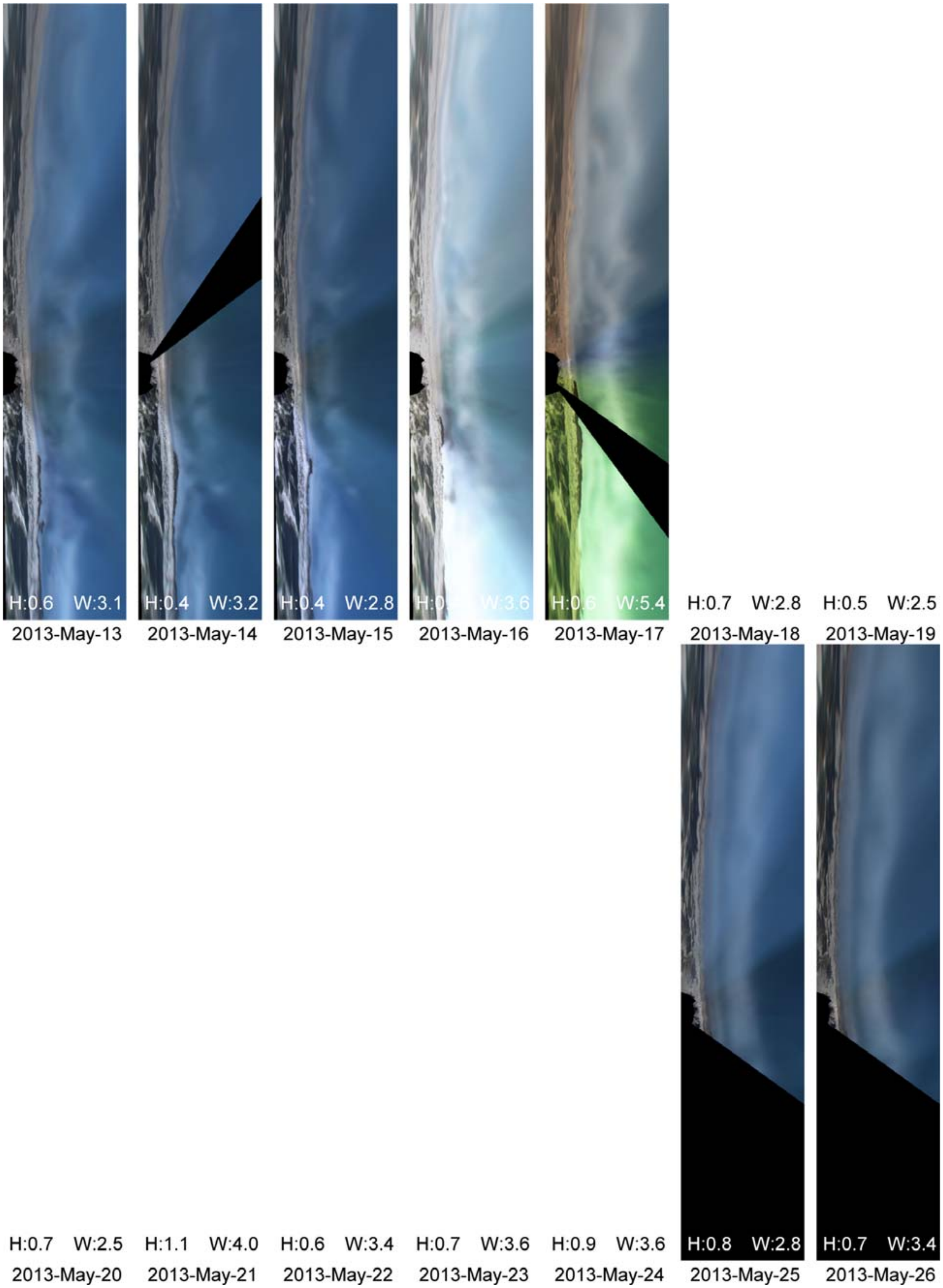
2013-May-02
H:1.0 W:
2013-May-03
H:0.5 W:3.4
2013-May-04
W:3.0
2013-May-05
H:0.5 W:1.3
2013-May-06
H:0.6 W:0.8
2013-May-07
H:0.8 W:5.8
2013-May-08
W:18.1
2013-May-09
H:1.5 W:11.9
2013-May-10
H:1.4 W:12.2
2013-May-11
H:1.0 W:3.4
2013-May-12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2013-May-13
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2013-May-14
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2013-May-15
W:3.6
2013-May-16
H:0.6 W:5.4
2013-May-17
H:0.7 W:2.8
2013-May-18
H:0.5 W:2.5
2013-May-19
H:0.7 W:2.5
2013-May-20
H:1.1 W:4.0
2013-May-21
H:0.6 W:3.4
2013-May-22
H:0.7 W:3.6
2013-May-23
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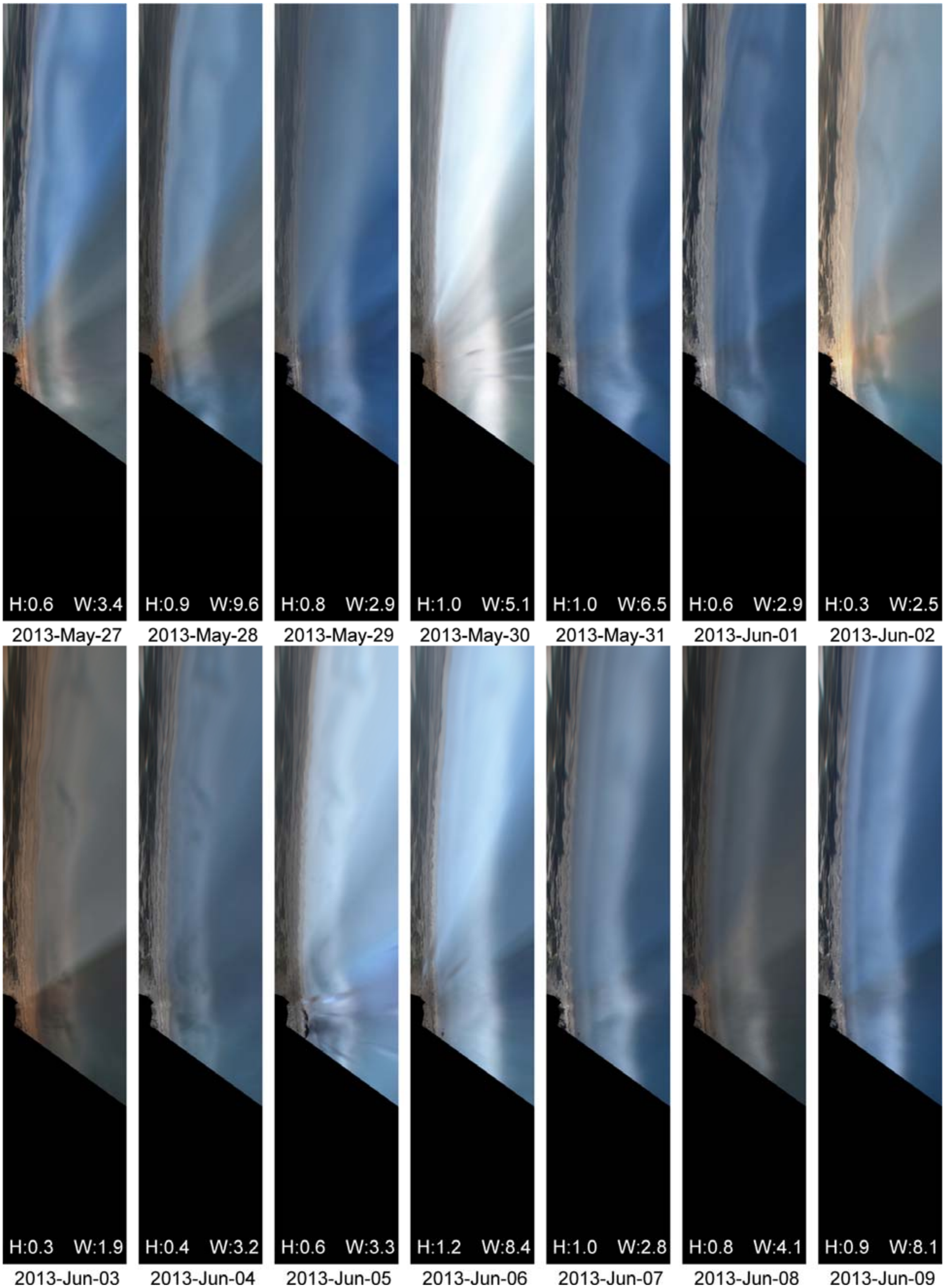
2013-May-24
H:0.8 W:2.8
2013-May-25
H:0.7 W:3.4
2013-May-26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2013-May-27
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2013-May-28
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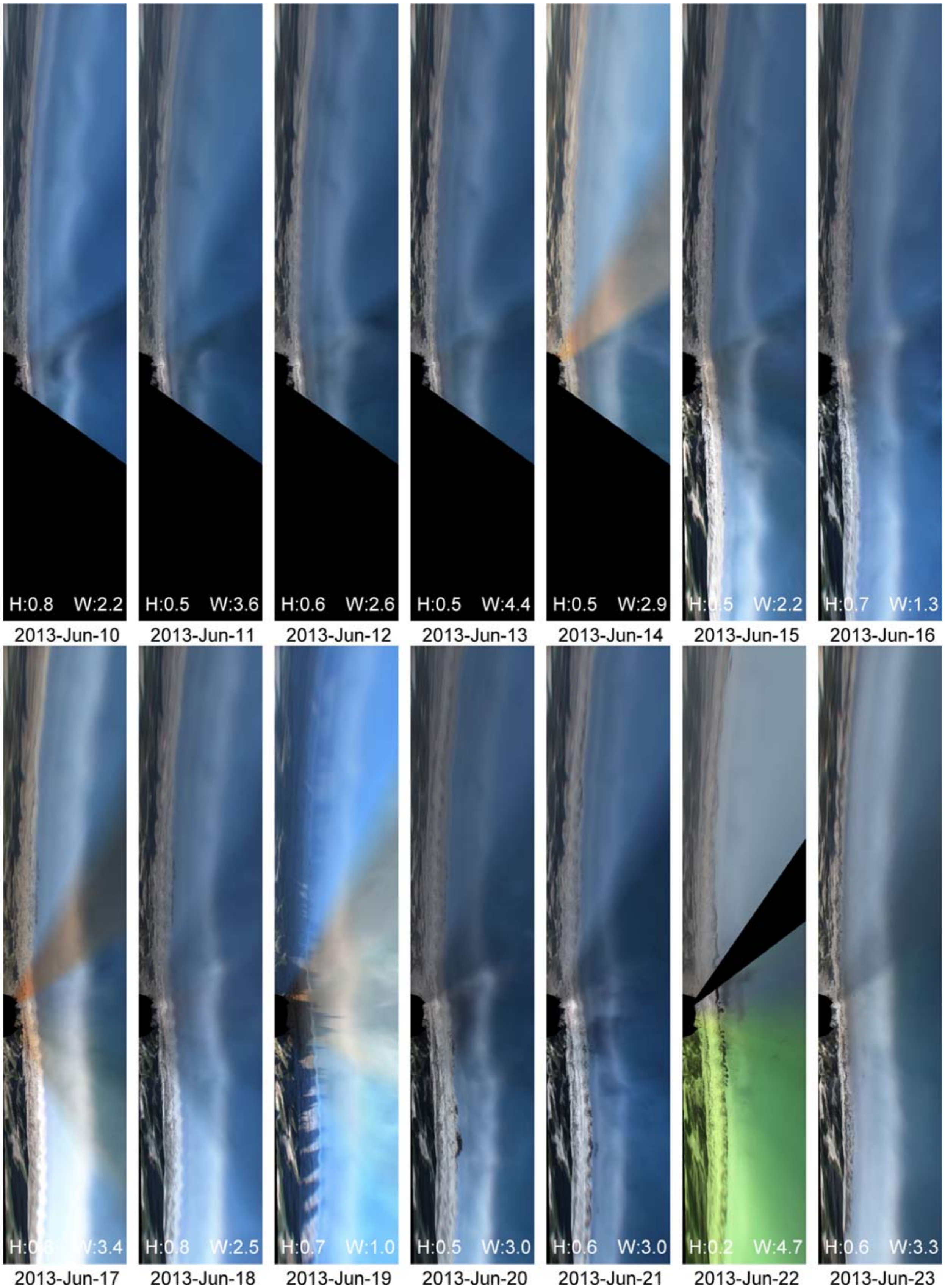
2013-May-29
H:1.0 W:5.1
2013-May-30
H:1.0 W:6.5
2013-May-31
H:0.6 W:2.9
2013-Jun-01
H:0.3 W:2.5
2013-Jun-02
H:0.3 W:1.9
2013-Jun-03
H:0.4 W:3.2
2013-Jun-04
H:0.6 W:3.3
2013-Jun-05
H:1.2 W:8.4
2013-Jun-06
H:1.0 W:2.8
2013-Jun-07
H:0.8 W:4.1
2013-Jun-08
H:0.9 W:8.1
2013-Jun-09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2013-Jun-12
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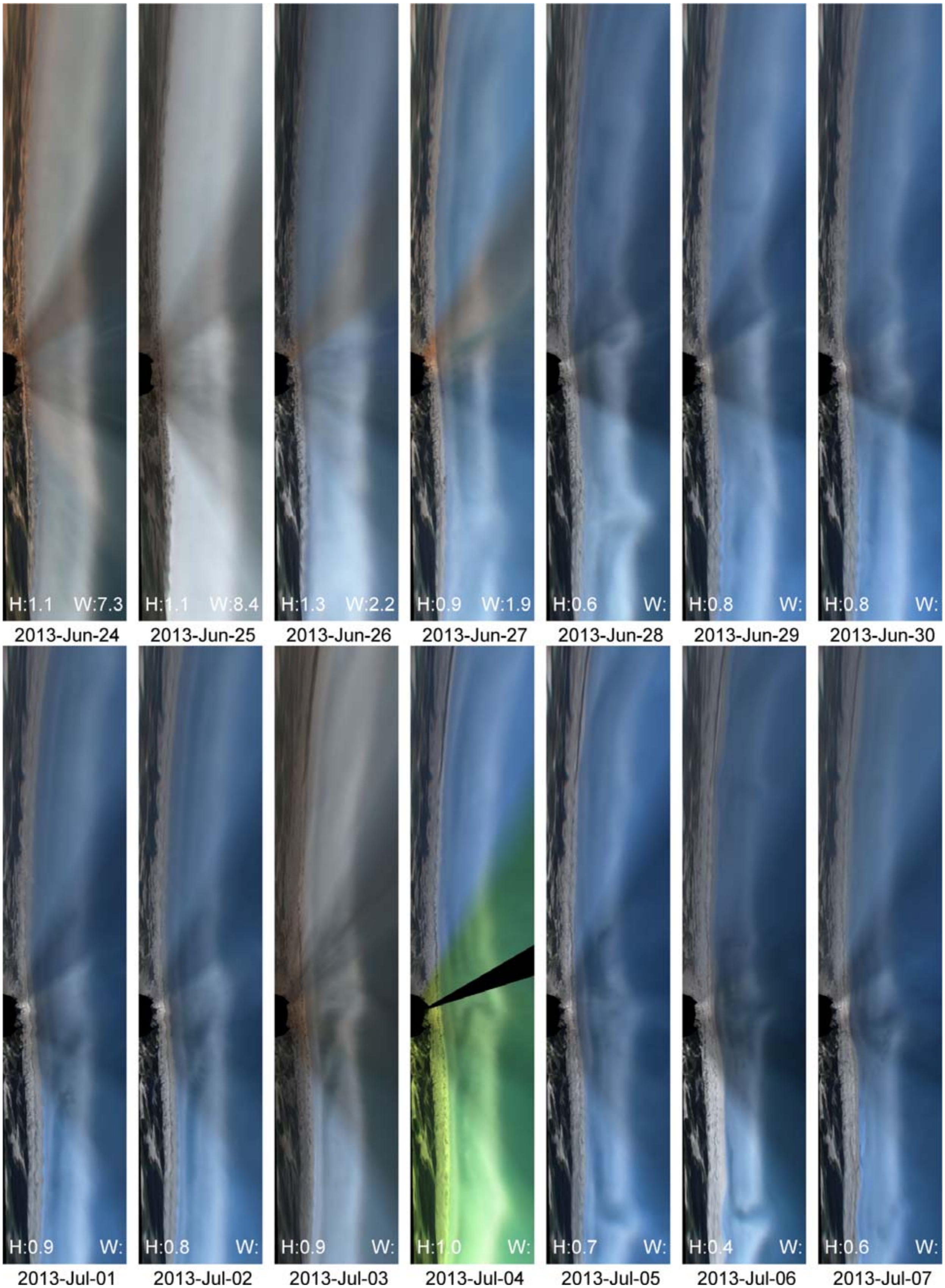
2013-Jun-13
H:0.5 W:2.9
2013-Jun-14
W:2.2
2013-Jun-15
H:0.7 W:1.3
2013-Jun-16
2013-Jun-17
H:0.8 W:2.5
2013-Jun-18
H:0.7 W:1.0
2013-Jun-19
H:0.5 W:3.0
2013-Jun-20
H:0.6 W:3.0
2013-Jun-21
H:0.2 W:4.7
2013-Jun-22
H:0.6 W:3.3
2013-Jun-23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2013-Jun-24
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2013-Jun-25
H:1.3 W:2.2
2013-Jun-26
H:0.9 W:1.9
2013-Jun-27
H:0.6 W:
2013-Jun-28
H:0.8 W:
2013-Jun-29
H:0.8 W:
2013-Jun-30
H:0.9 W:
2013-Jul-01
H:0.8 W:
2013-Jul-02
H:0.9 W:
2013-Jul-03
H:1.0 W:
2013-Jul-04
H:0.7 W:
2013-Jul-05
H:0.4 W:
2013-Jul-06
H:0.6 W:
2013-Jul-07

2013-Jul-08

2013-Jul-09

H:0.9 W:
2013-Jul-10

H:0.8 W:
2013-Jul-11

H:0.7 W:
2013-Jul-12

H:0.7 W:
2013-Jul-13

H:0.7 W:4.1
2013-Jul-14

2013-Jul-15

2013-Jul-16

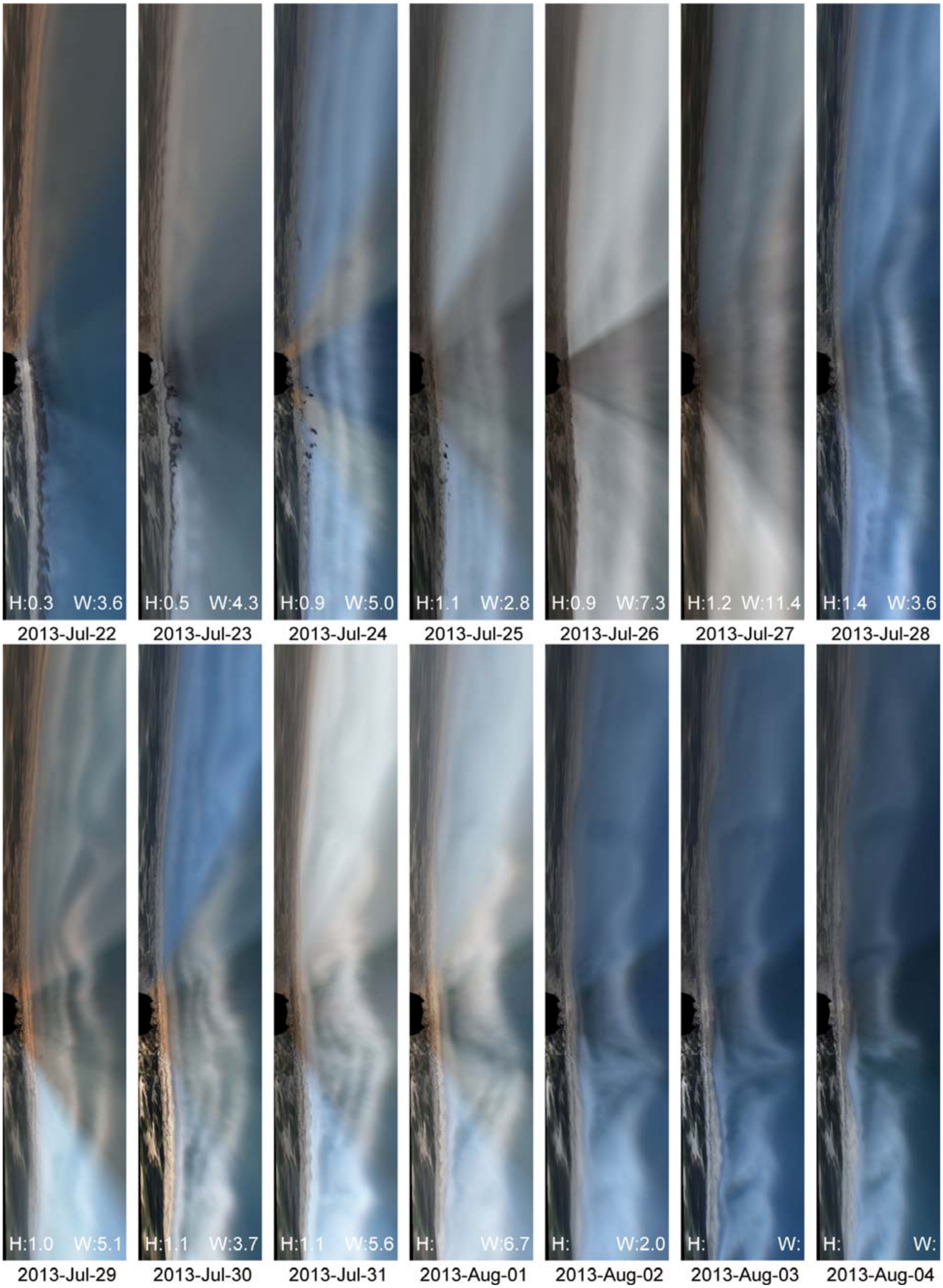
2013-Jul-17

2013-Jul-18

2013-Jul-19

2013-Jul-20

2013-Jul-21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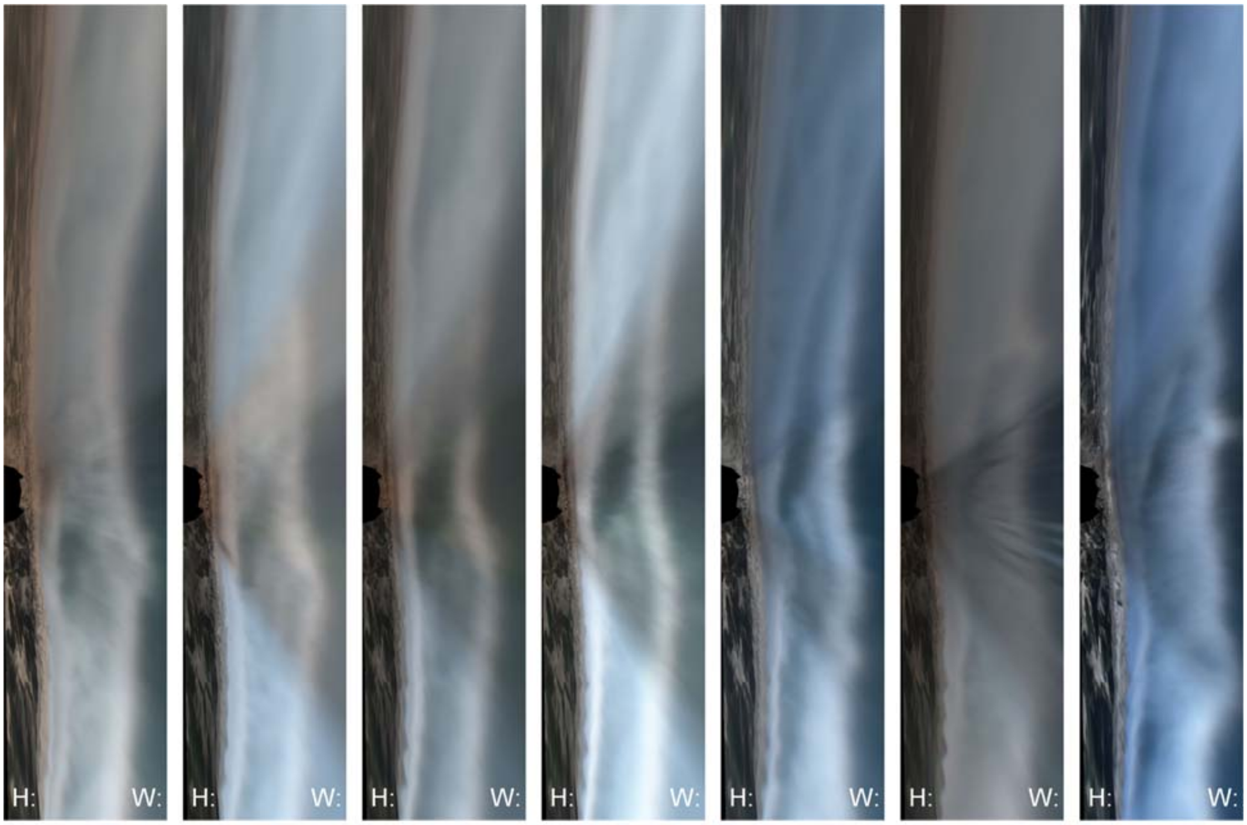
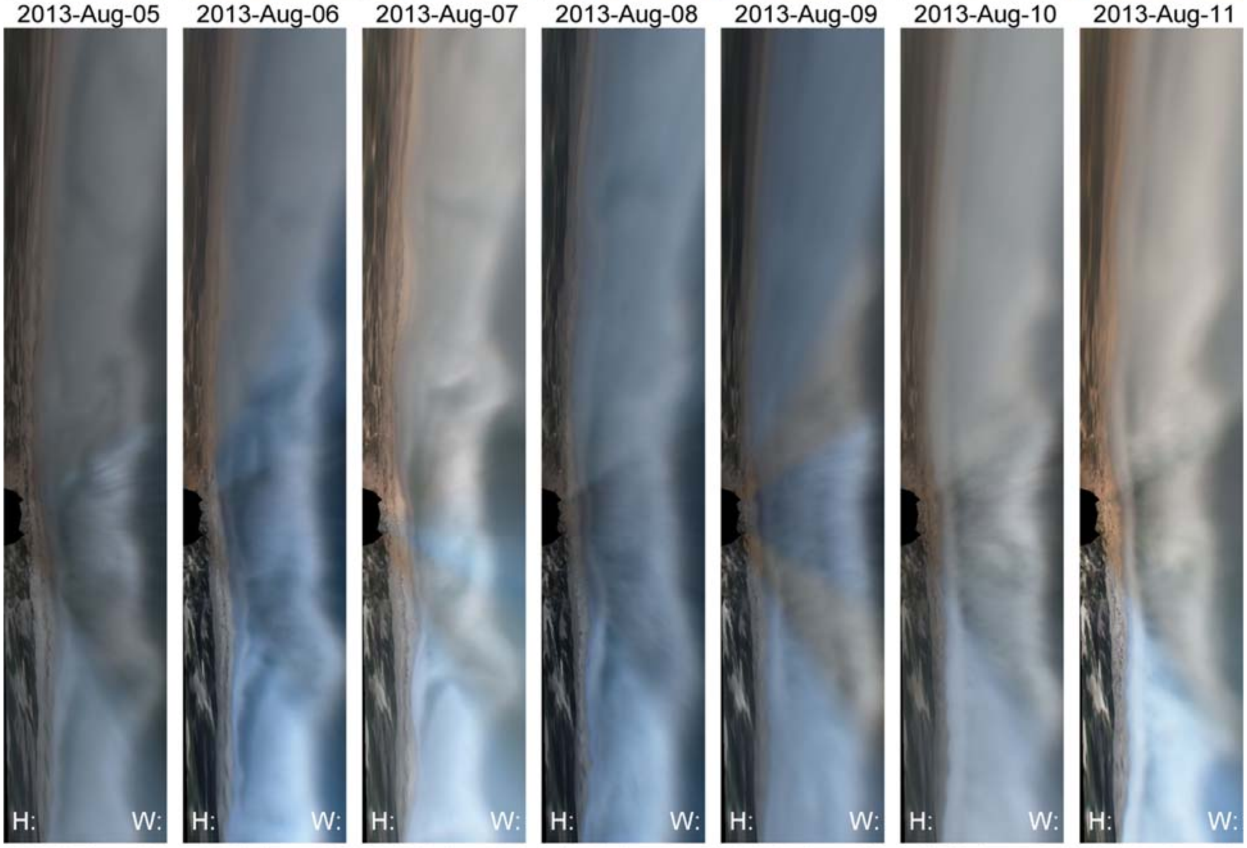
2013-Jul-22
H:0.5 W:4.3
2013-Jul-23
H:0.9 W:5.0
2013-Jul-24
H:1.1 W:2.8
2013-Jul-25
H:0.9 W:7.3
2013-Jul-26
H:1.2 W:11.4
2013-Jul-27
H:1.4 W:3.6
2013-Jul-28
H:1.0 W:5.1
2013-Jul-29
H:1.1 W:3.7
2013-Jul-30
H:1.1 W:5.6
2013-Jul-31
H: W:6.7
2013-Aug-01
H: W:2.0
2013-Aug-02
H: W:
2013-Aug-03
H: W:
2013-Aug-04



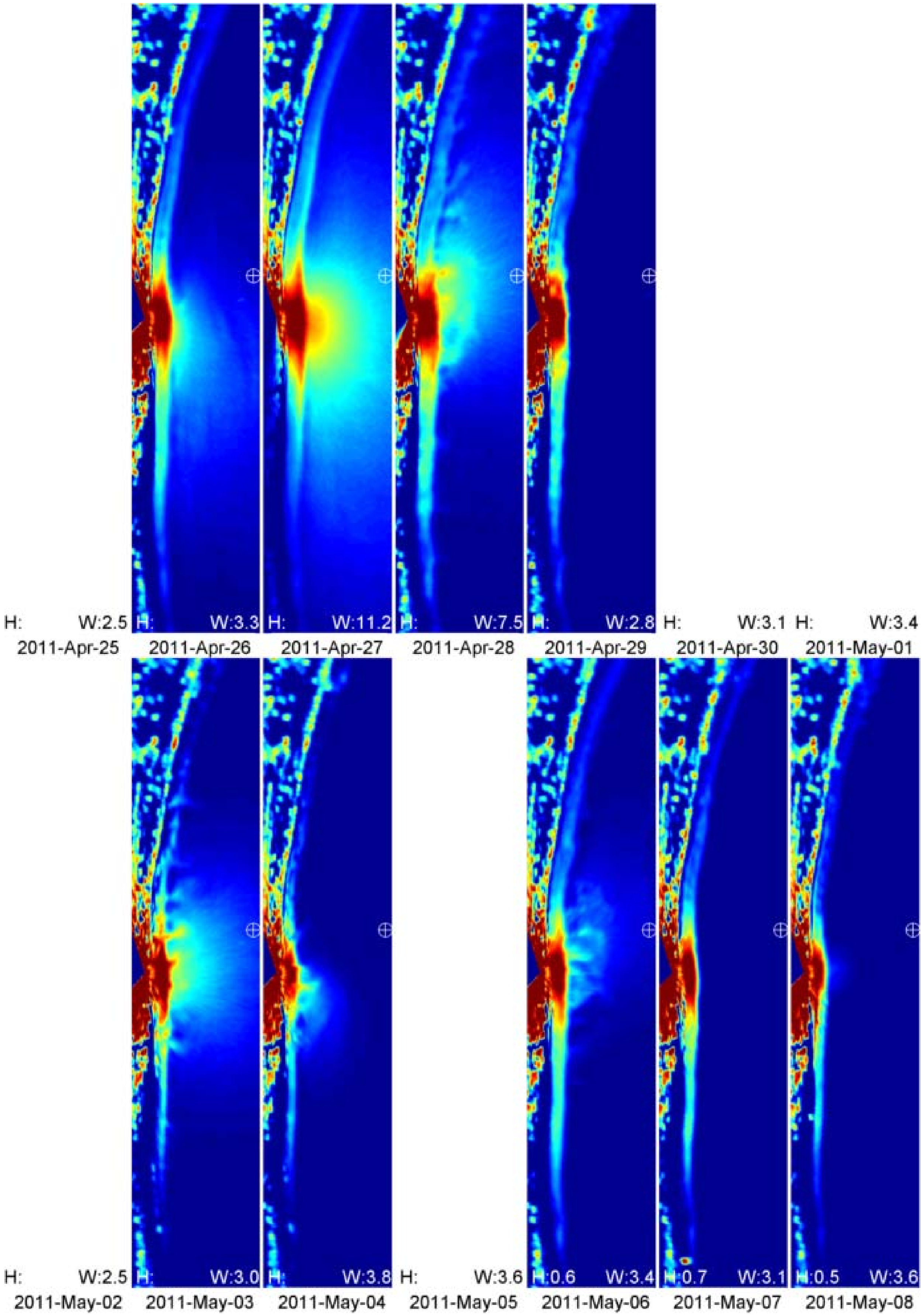
2013-Aug-05 2013-Aug-06 2013-Aug-07 2013-Aug-08 2013-Aug-09 2013-Aug-10 2013-Aug-11

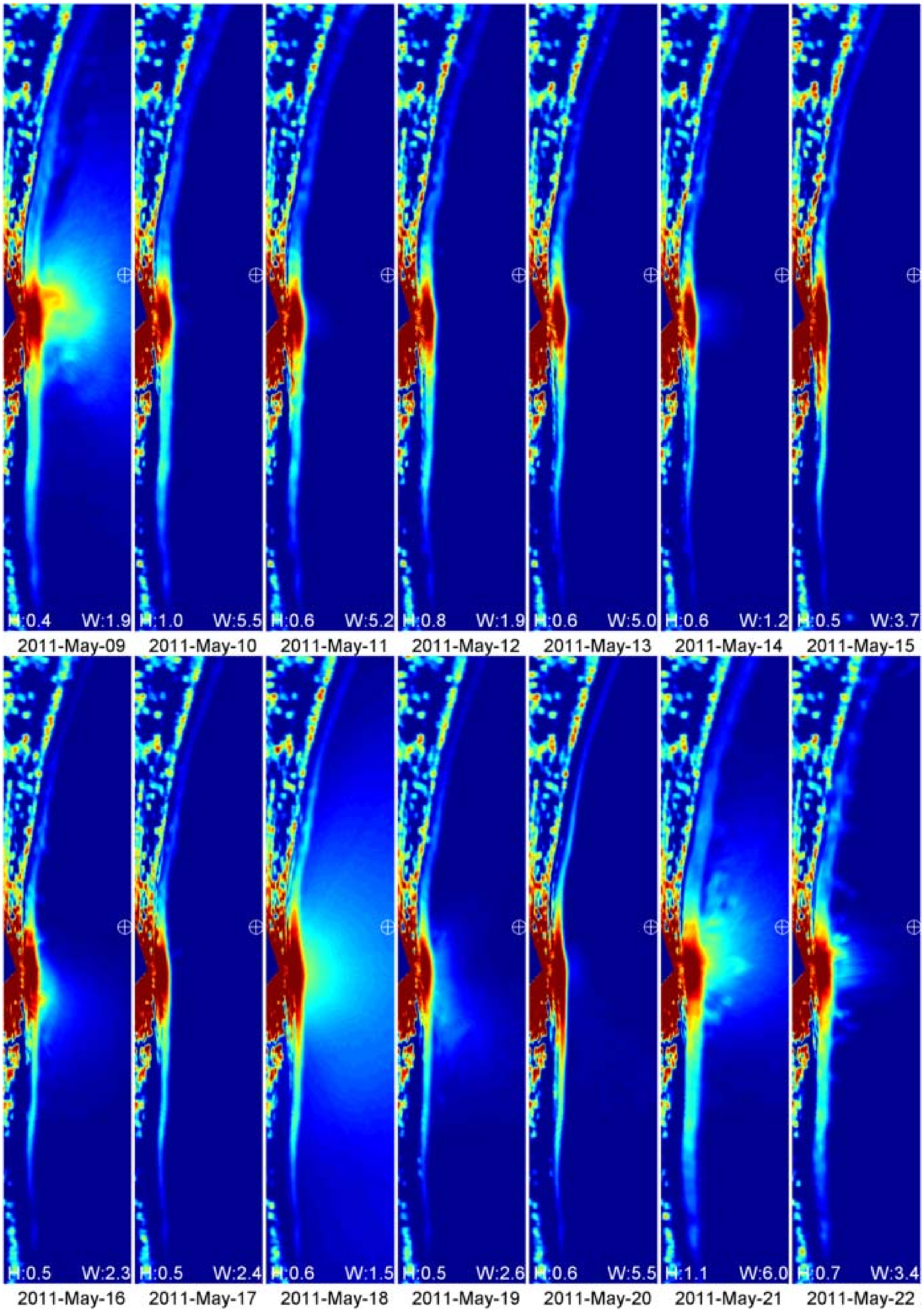


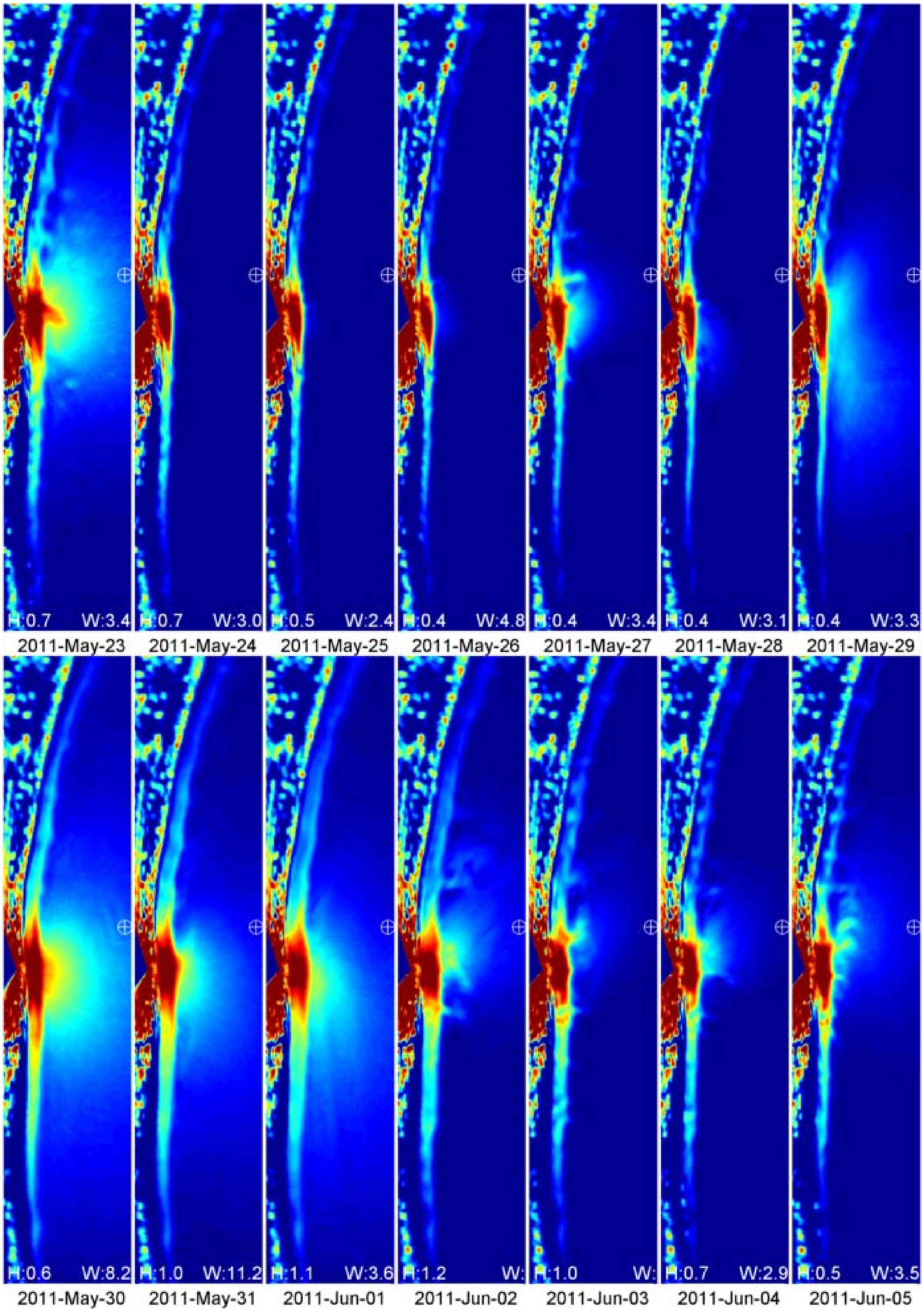
2013-Aug-12 2013-Aug-13 2013-Aug-14 2013-Aug-15 2013-Aug-16 2013-Aug-17 2013-Aug-18

APPENDIX 2 RADAR IMAGES

Daily radar time exposure images in a box extending 550m offshore and 3000m alongshore. The corresponding wave height (H) in metres and wind speed (W) in ms^{-1} are shown at the bottom of each image and the AWAC location is marked with a cross.


H: W:2.5
2011-Apr-25
H: W:3.3
2011-Apr-26
H: W:11.2
2011-Apr-27
H: W:7.5
2011-Apr-28
H: W:2.8
2011-Apr-29
H: W:3.1
2011-Apr-30
H: W:3.4
2011-May-01
H: W:2.5
2011-May-02
H: W:3.0
2011-May-03
H: W:3.8
2011-May-04
H: W:3.6
2011-May-05
H:0.6 W:3.4
2011-May-06
H:0.7 W:3.1
2011-May-07
H:0.5 W:3.6
2011-May-08


H:0.4 W:1.9
2011-May-09
H:1.0 W:5.5
2011-May-10
H:0.6 W:5.2
2011-May-11
H:0.8 W:1.9
2011-May-12
H:0.6 W:5.0
2011-May-13
H:0.6 W:1.2
2011-May-14
H:0.5 W:3.7
2011-May-15
H:0.5 W:2.3
2011-May-16
H:0.5 W:2.4
2011-May-17
H:0.6 W:1.5
2011-May-18
H:0.5 W:2.6
2011-May-19
H:0.6 W:5.5
2011-May-20
H:1.1 W:6.0
2011-May-21
H:0.7 W:3.4
2011-May-22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2011-May-23
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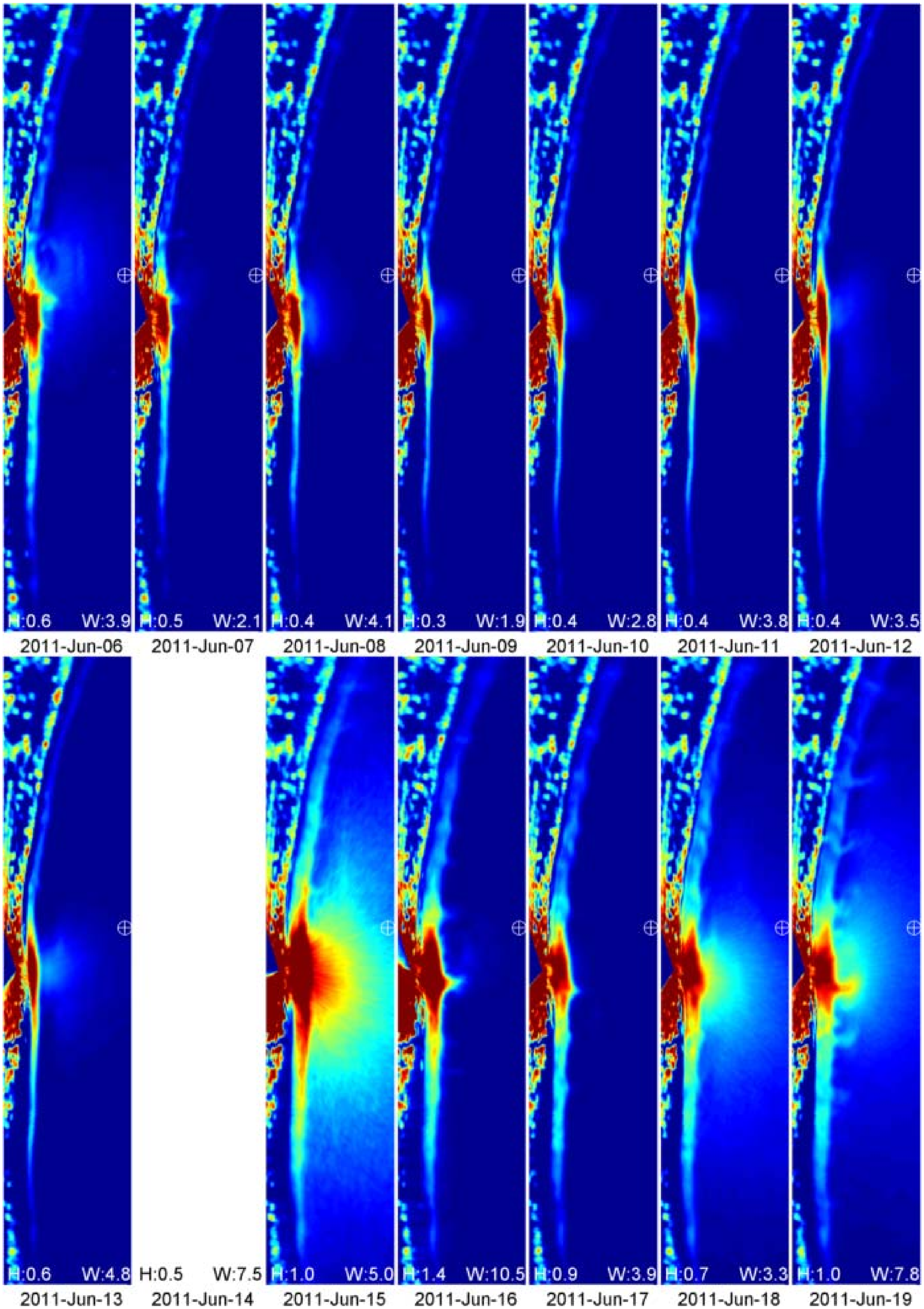
2011-May-24
H:0.5 W:2.4
2011-May-25
H:0.4 W:4.8
2011-May-26
H:0.4 W:3.4
2011-May-27
H:0.4 W:3.1
2011-May-28
H:0.4 W:3.3
2011-May-29
H:0.6 W:8.2
2011-May-30
H:1.0 W:11.2
2011-May-31
H:1.1 W:3.6
2011-Jun-01
H:1.2 W:
2011-Jun-02
H:1.0 W:
2011-Jun-03
H:0.7 W:2.9
2011-Jun-04
H:0.5 W:3.5
2011-Jun-05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2011-Jun-06
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2011-Jun-07
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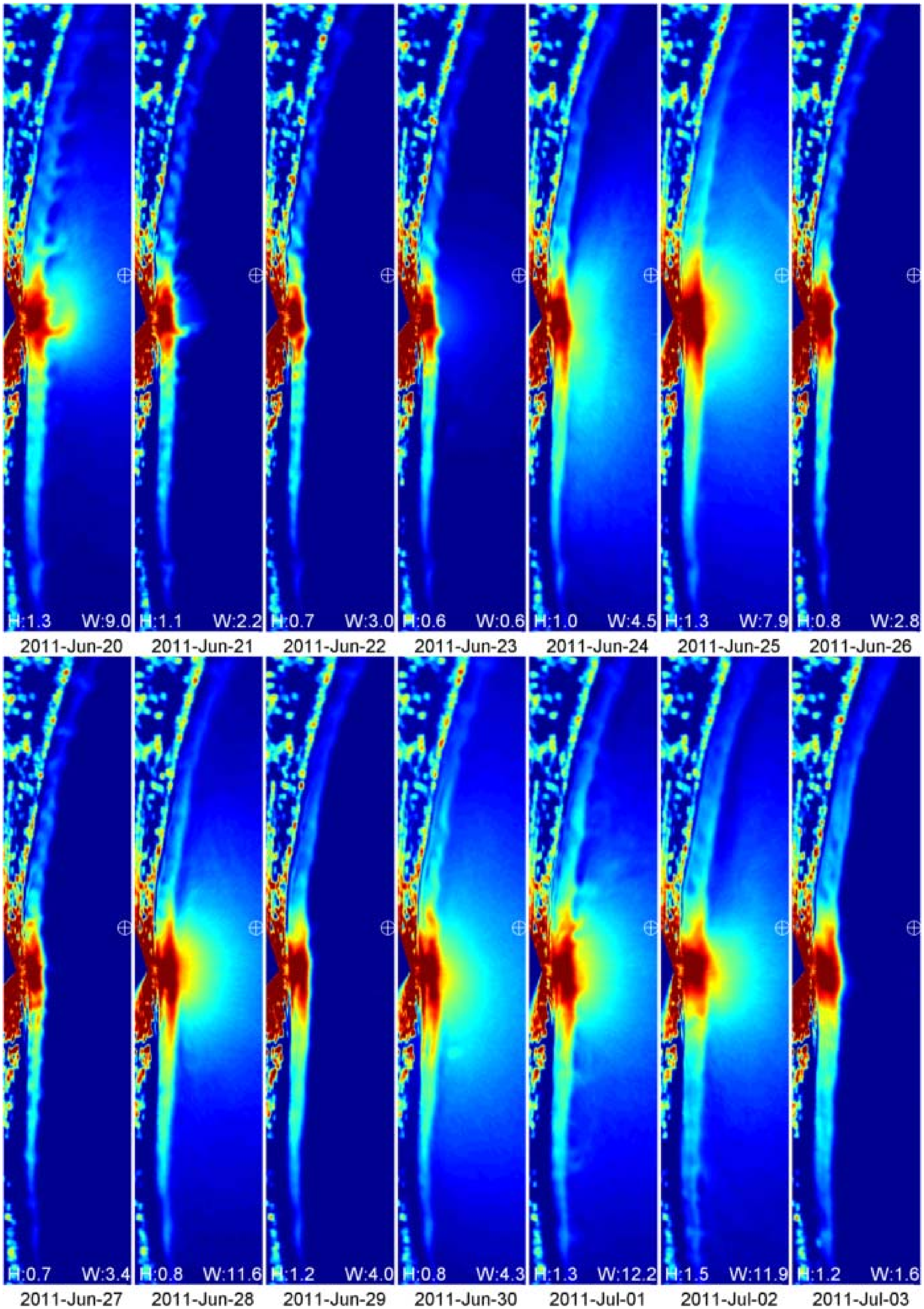
2011-Jun-08
H:0.3 W:1.9
2011-Jun-09
H:0.4 W:2.8
2011-Jun-10
H:0.4 W:3.8
2011-Jun-11
H:0.4 W:3.5
2011-Jun-12
H:0.6 W:4.8
2011-Jun-13
H:0.5 W:7.5
2011-Jun-14
H:1.0 W:5.0
2011-Jun-15
H:1.4 W:10.5
2011-Jun-16
H:0.9 W:3.9
2011-Jun-17
H:0.7 W:3.3
2011-Jun-18
H:1.0 W:7.8
2011-Jun-19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2011-Jun-20
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2011-Jun-21
H:0.7 W:3.0
2011-Jun-22
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2011-Jun-23
H:1.0 W:4.5
2011-Jun-24
H:1.3 W:7.9
2011-Jun-25
H:0.8 W:2.8
2011-Jun-26
H:0.7 W:3.4
2011-Jun-27
H:0.8 W:11.6
2011-Jun-28
H:1.2 W:4.0
2011-Jun-29
H:0.8 W:4.3
2011-Jun-30
H:1.3 W:12.2
2011-Jul-01
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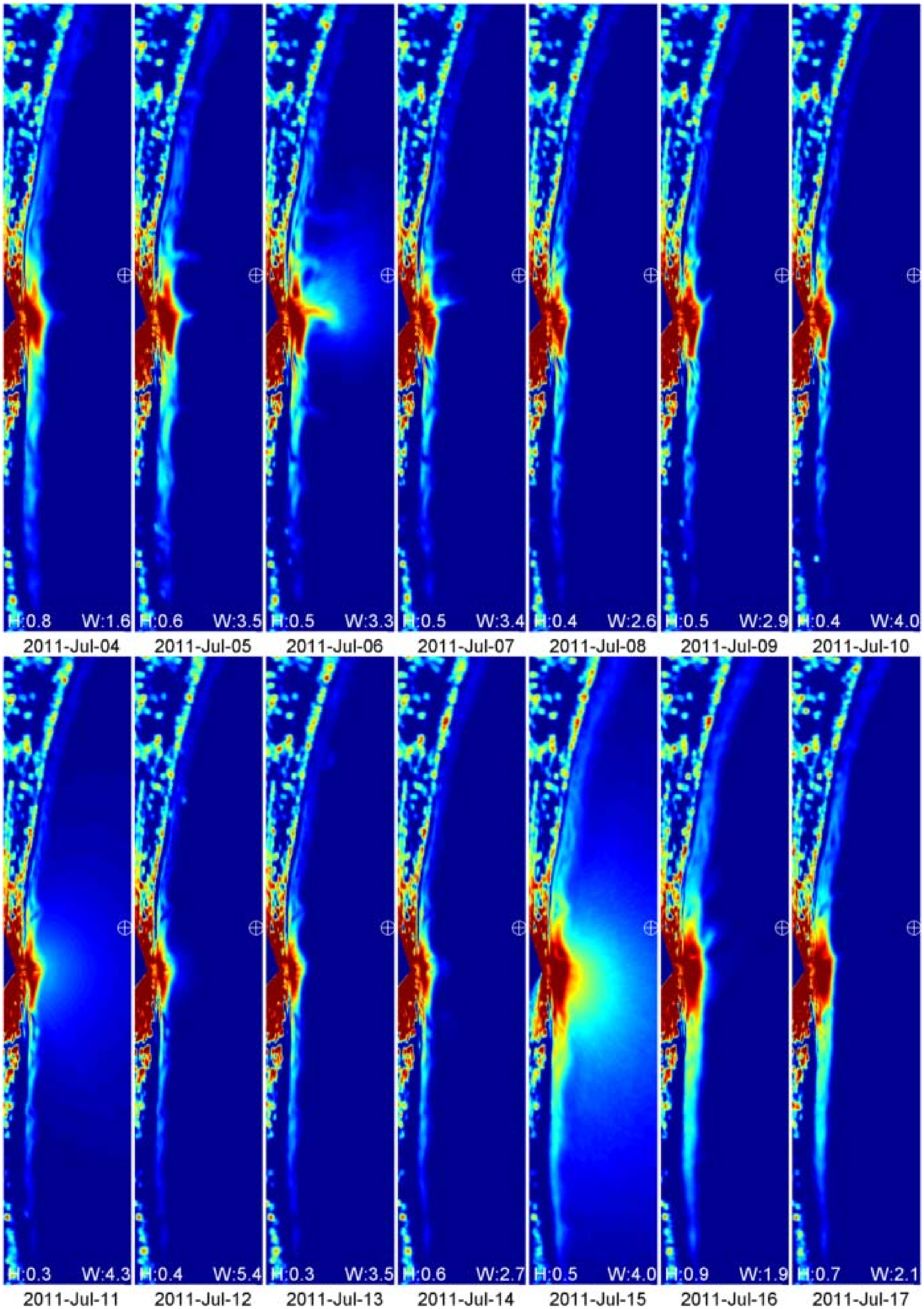
2011-Jul-02
H:1.2 W:1.6
2011-Jul-03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2011-Jul-04
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2011-Jul-05
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2011-Jul-06
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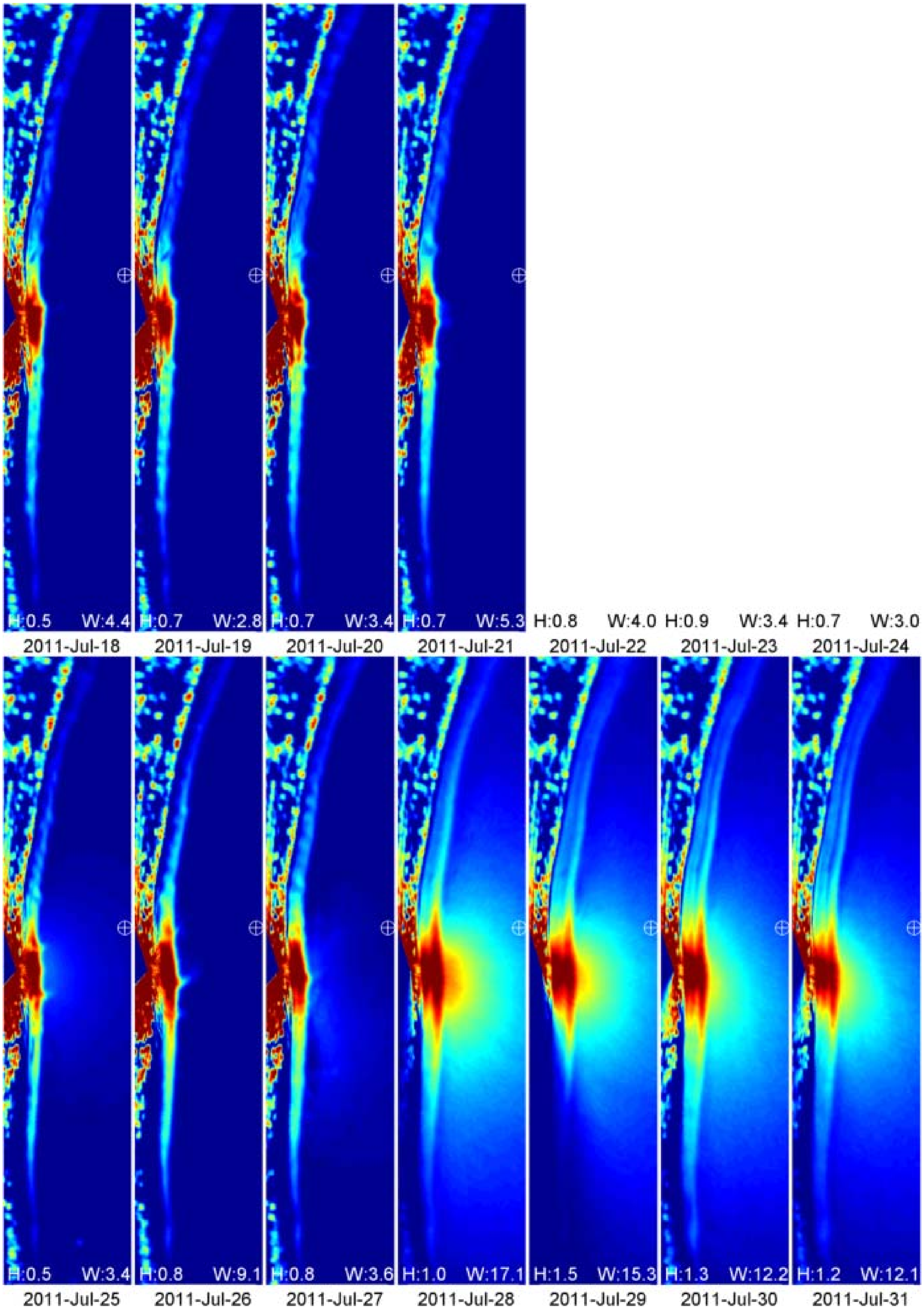
2011-Jul-07
H:0.4 W:2.6
2011-Jul-08
H:0.5 W:2.9
2011-Jul-09
H:0.4 W:4.0
2011-Jul-10
H:0.3 W:4.3
2011-Jul-11
H:0.4 W:5.4
2011-Jul-12
H:0.3 W:3.5
2011-Jul-13
H:0.6 W:2.7
2011-Jul-14
H:0.5 W:4.0
2011-Jul-15
H:0.9 W:1.9
2011-Jul-16
H:0.7 W:2.1
2011-Jul-17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2011-Jul-18
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2011-Jul-19
H:0.7 W:3.4
2011-Jul-20
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2011-Jul-21
H:0.8 W:4.0
2011-Jul-22
H:0.9 W:3.4
2011-Jul-23
H:0.7 W:3.0
2011-Jul-24
H:0.5 W:3.4
2011-Jul-25
H:0.8 W:9.1
2011-Jul-26
H:0.8 W:3.6
2011-Jul-27
H:1.0 W:17.1
2011-Jul-28
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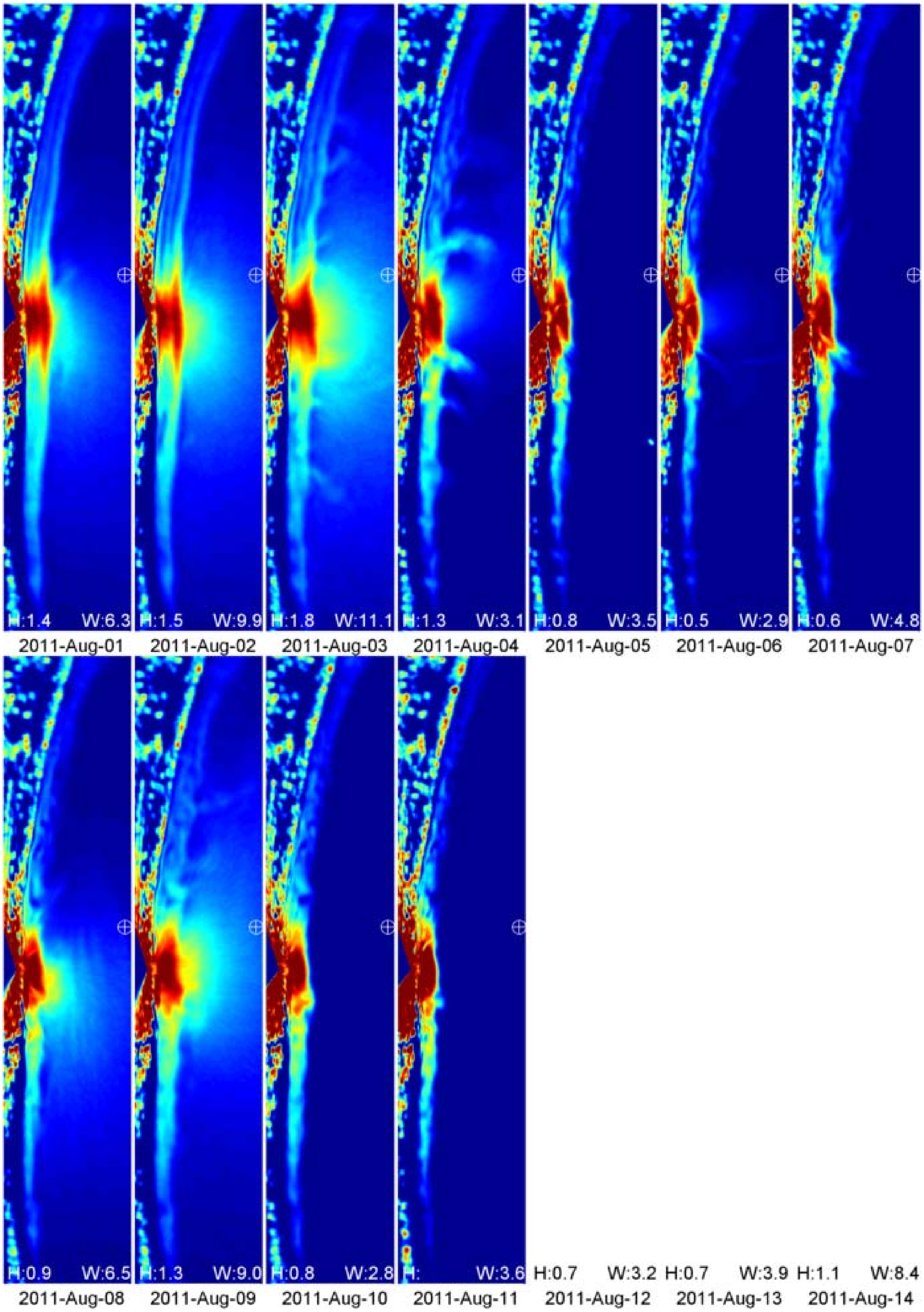
2011-Jul-29
H:1.3 W:12.2
2011-Jul-30
H:1.2 W:12.1
2011-Jul-31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2011-Aug-02
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2011-Aug-03
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2011-Aug-04
H:0.8 W:3.5
2011-Aug-05
H:0.5 W:2.9
2011-Aug-06
H:0.6 W:4.8
2011-Aug-07
H:0.9 W:6.5
2011-Aug-08
H:1.3 W:9.0
2011-Aug-09
H:0.8 W:2.8
2011-Aug-10
H: W:3.6
2011-Aug-11
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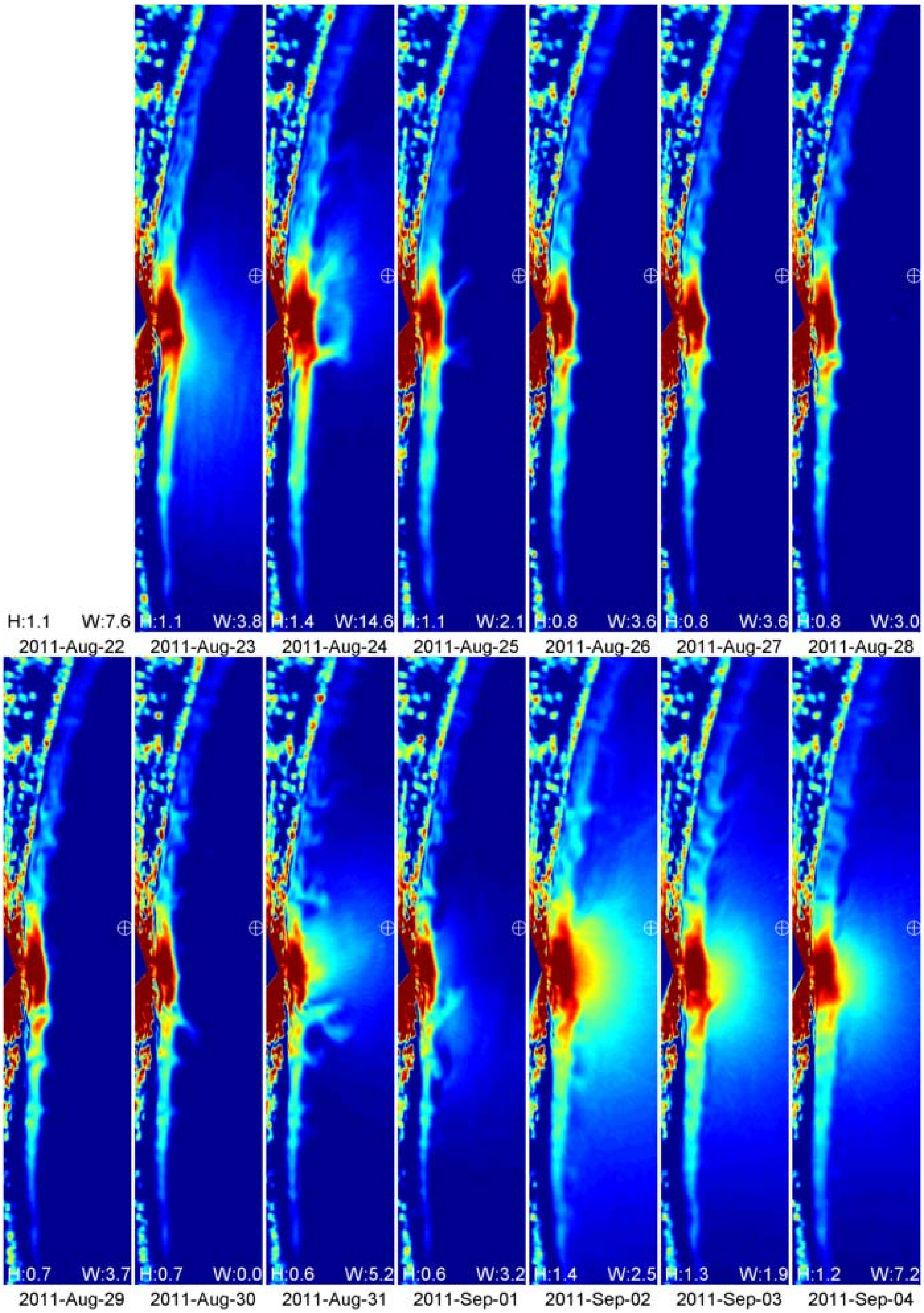
2011-Aug-12
H:0.7 W:3.9
2011-Aug-13
H:1.1 W:8.4
2011-Aug-14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2011-Aug-22
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2011-Aug-24
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2011-Aug-25
H:0.8 W:3.6
2011-Aug-26
H:0.8 W:3.6
2011-Aug-27
H:0.8 W:3.0
2011-Aug-28
H:0.7 W:3.7
2011-Aug-29
H:0.7 W:0.0
2011-Aug-30
H:0.6 W:5.2
2011-Aug-31
H:0.6 W:3.2
2011-Sep-01
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2011-Sep-02
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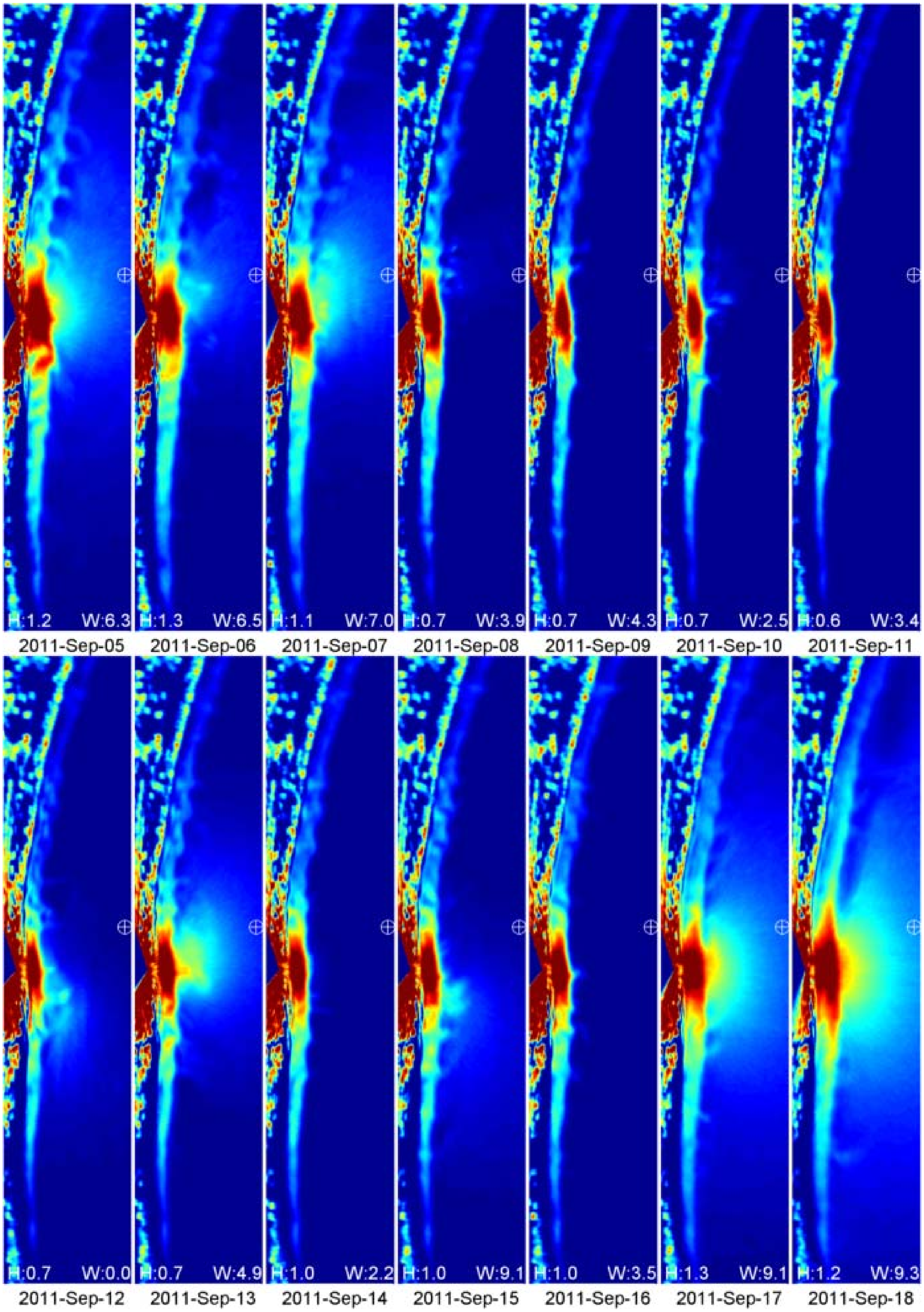
2011-Sep-04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2011-Sep-06
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2011-Sep-07
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2011-Sep-08
H:0.7 W:4.3
2011-Sep-09
H:0.7 W:2.5
2011-Sep-10
H:0.6 W:3.4
2011-Sep-11
H:0.7 W:0.0
2011-Sep-12
H:0.7 W:4.9
2011-Sep-13
H:1.0 W:2.2
2011-Sep-14
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2011-Sep-15
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2011-Sep-17
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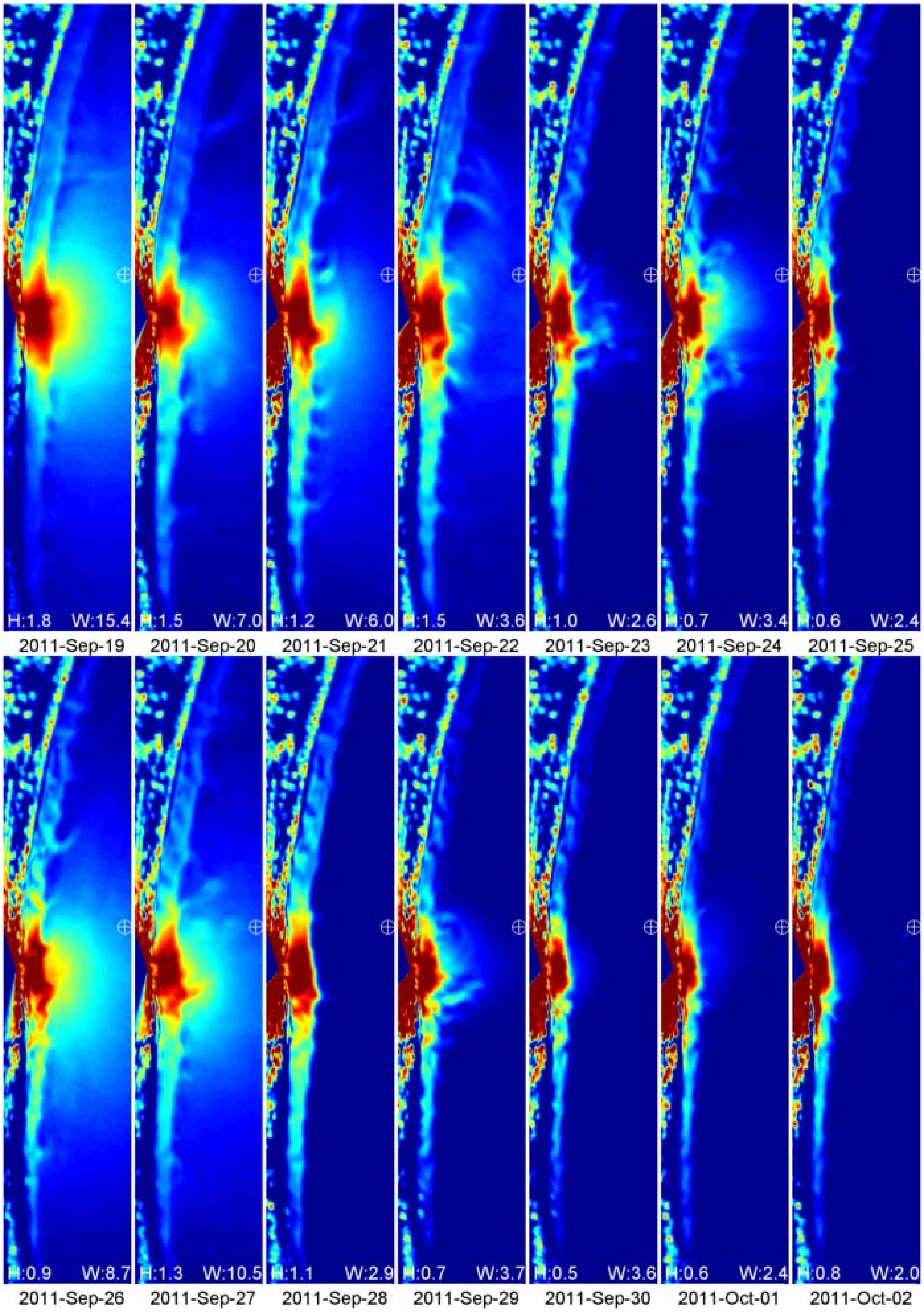
2011-Sep-18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2011-Sep-21
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2011-Sep-22
H:1.0 W:2.6
2011-Sep-23
H:0.7 W:3.4
2011-Sep-24
H:0.6 W:2.4
2011-Sep-25
H:0.9 W:8.7
2011-Sep-26
H:1.3 W:10.5
2011-Sep-27
H:1.1 W:2.9
2011-Sep-28
H:0.7 W:3.7
2011-Sep-29
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2011-Sep-30
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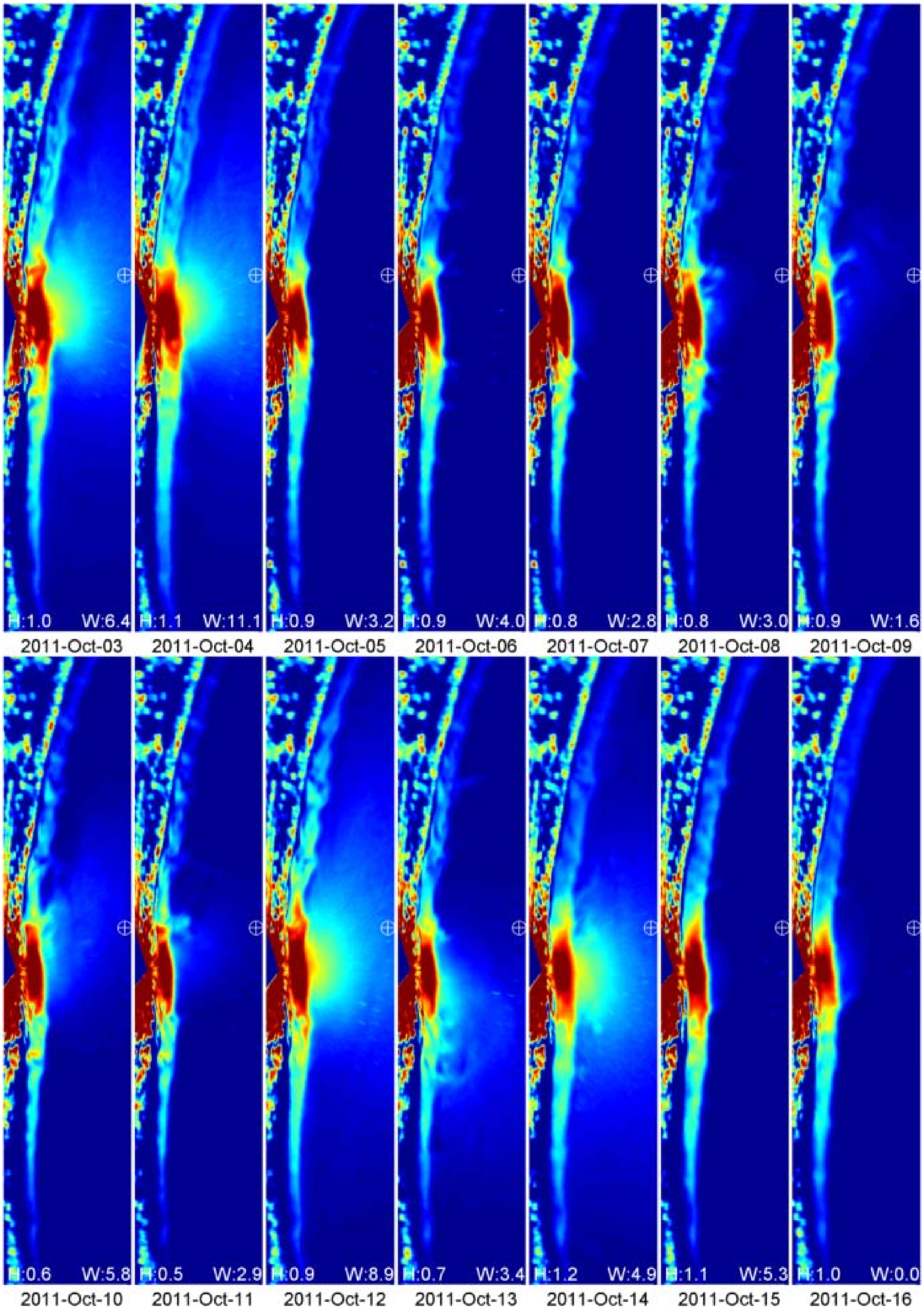
2011-Oct-01
H:0.8 W:2.0
2011-Oct-02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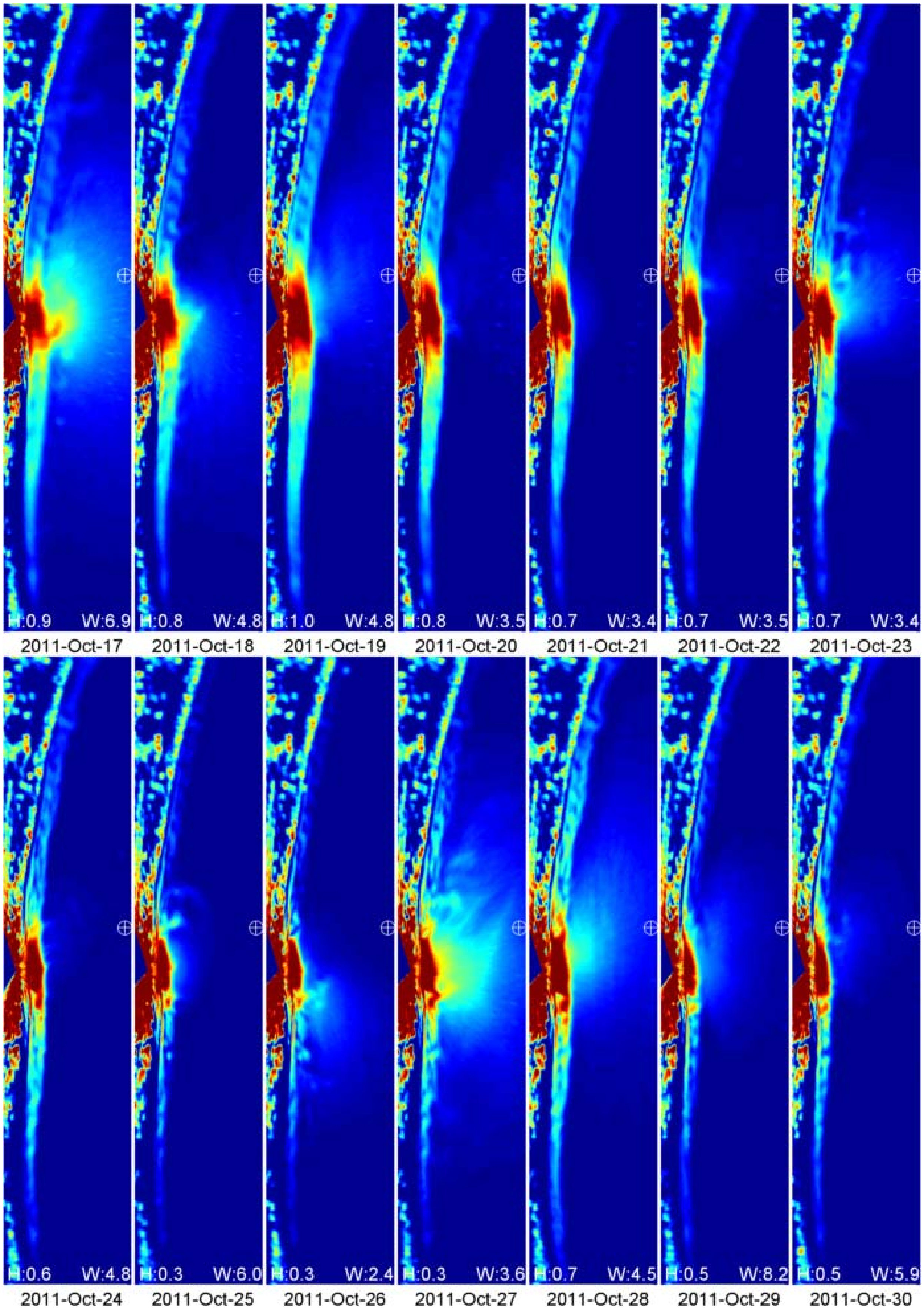
2011-Oct-04
H:0.9 W:3.2
2011-Oct-05
H:0.9 W:4.0
2011-Oct-06
H:0.8 W:2.8
2011-Oct-07
H:0.8 W:3.0
2011-Oct-08
H:0.9 W:1.6
2011-Oct-09
H:0.6 W:5.8
2011-Oct-10
H:0.5 W:2.9
2011-Oct-11
H:0.9 W:8.9
2011-Oct-12
H:0.7 W:3.4
2011-Oct-13
H:1.2 W:4.9
2011-Oct-14
H:1.1 W:5.3
2011-Oct-15
H:1.0 W:0.0
2011-Oct-16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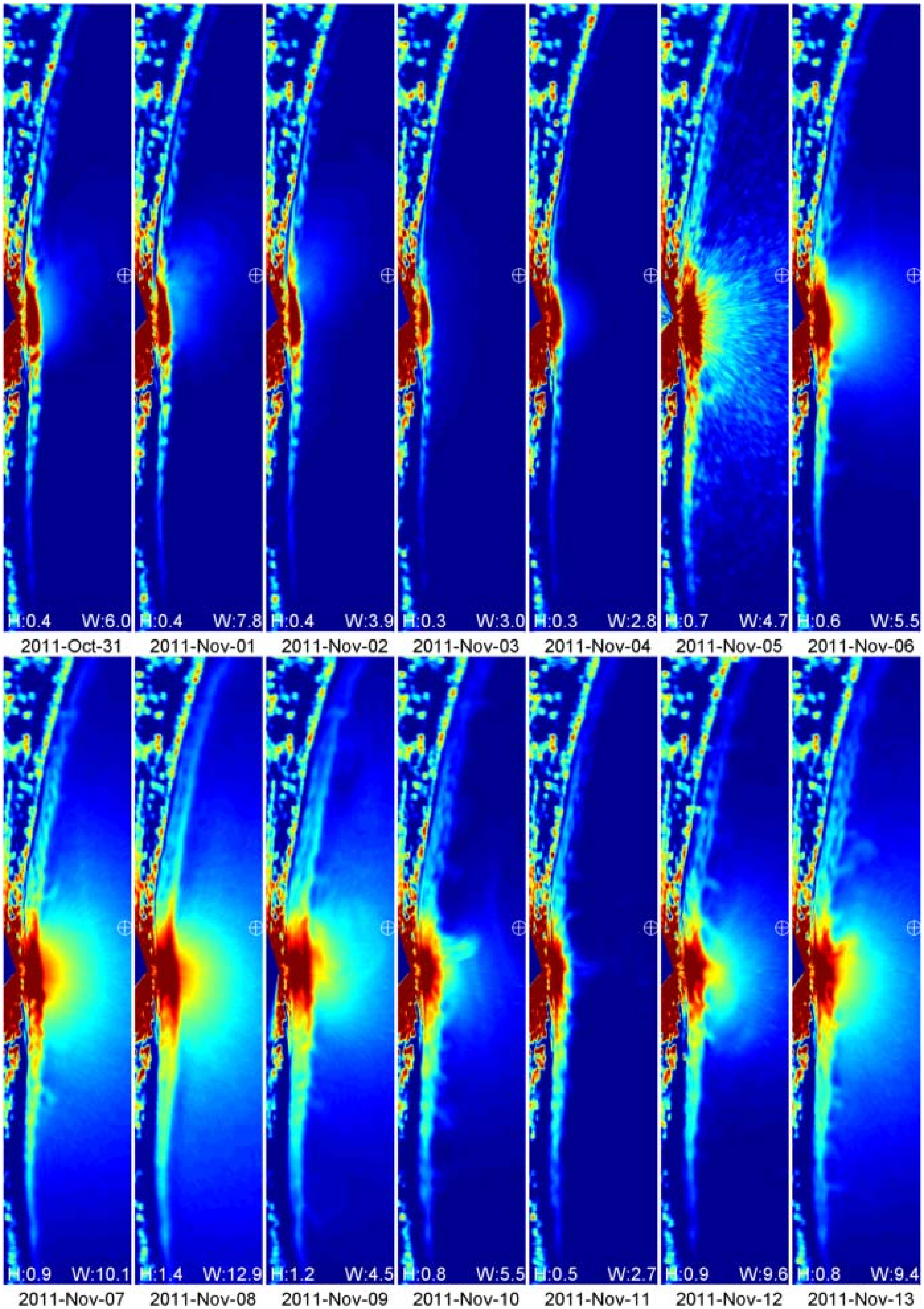
2011-Oct-17
H:0.8 W:4.8
2011-Oct-18
H:1.0 W:4.8
2011-Oct-19
H:0.8 W:3.5
2011-Oct-20
H:0.7 W:3.4
2011-Oct-21
H:0.7 W:3.5
2011-Oct-22
H:0.7 W:3.4
2011-Oct-23
H:0.6 W:4.8
2011-Oct-24
H:0.3 W:6.0
2011-Oct-25
H:0.3 W:2.4
2011-Oct-26
H:0.3 W:3.6
2011-Oct-27
H:0.7 W:4.5
2011-Oct-28
H:0.5 W:8.2
2011-Oct-29
H:0.5 W:5.9
2011-Oct-30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2011-Oct-31
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2011-Nov-01
H:0.4 W:3.9
2011-Nov-02
H:0.3 W:3.0
2011-Nov-03
H:0.3 W:2.8
2011-Nov-04
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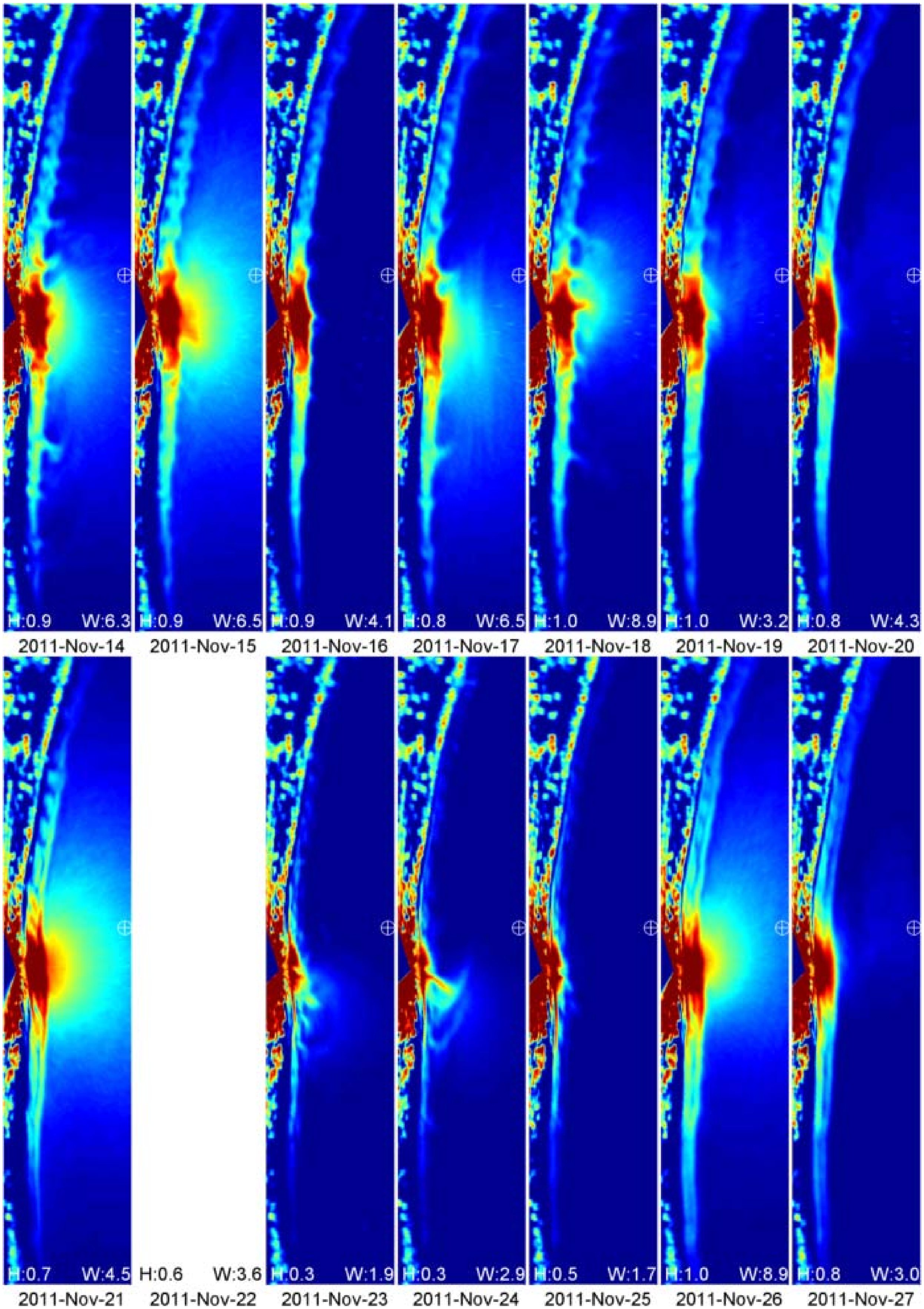
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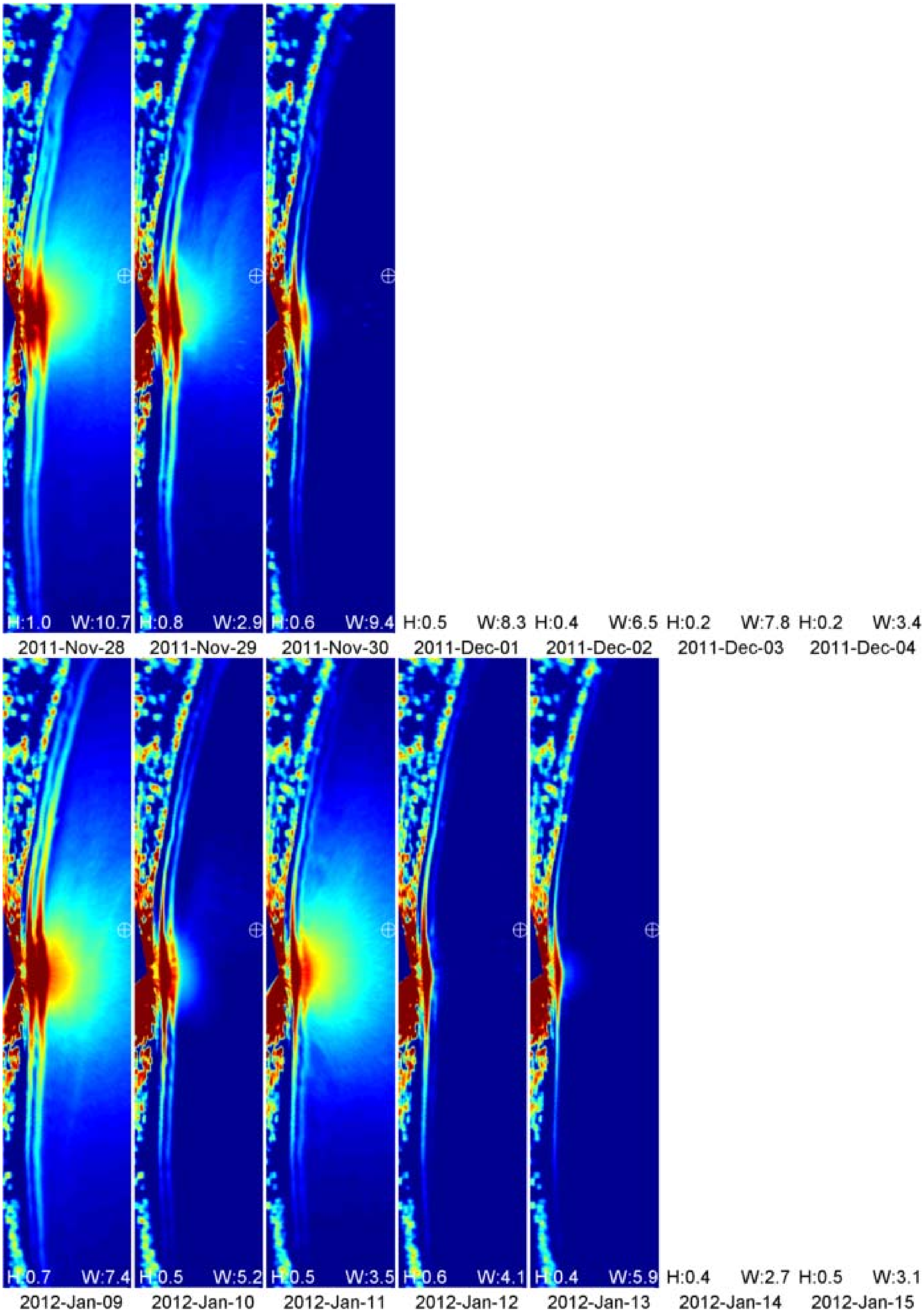
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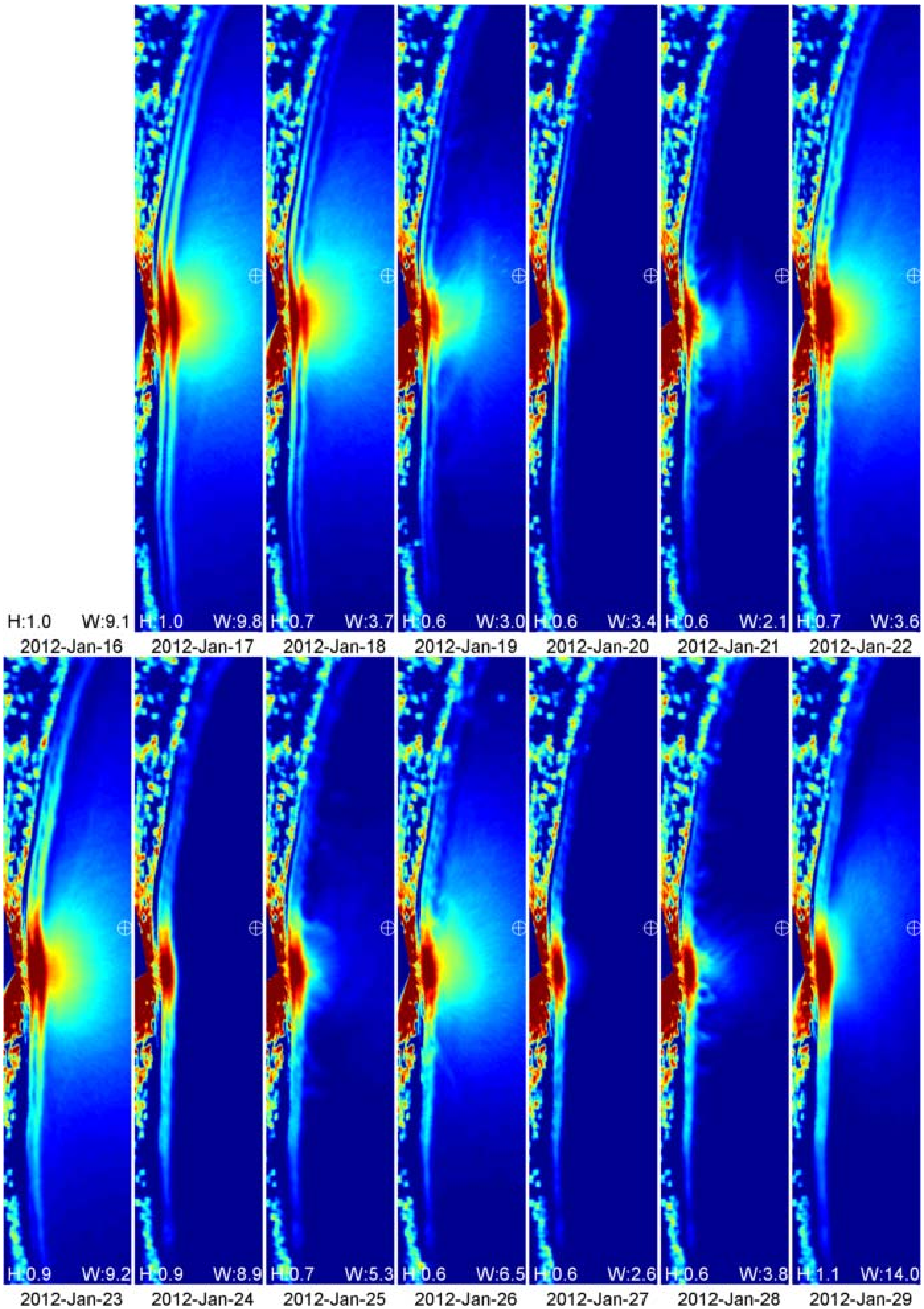
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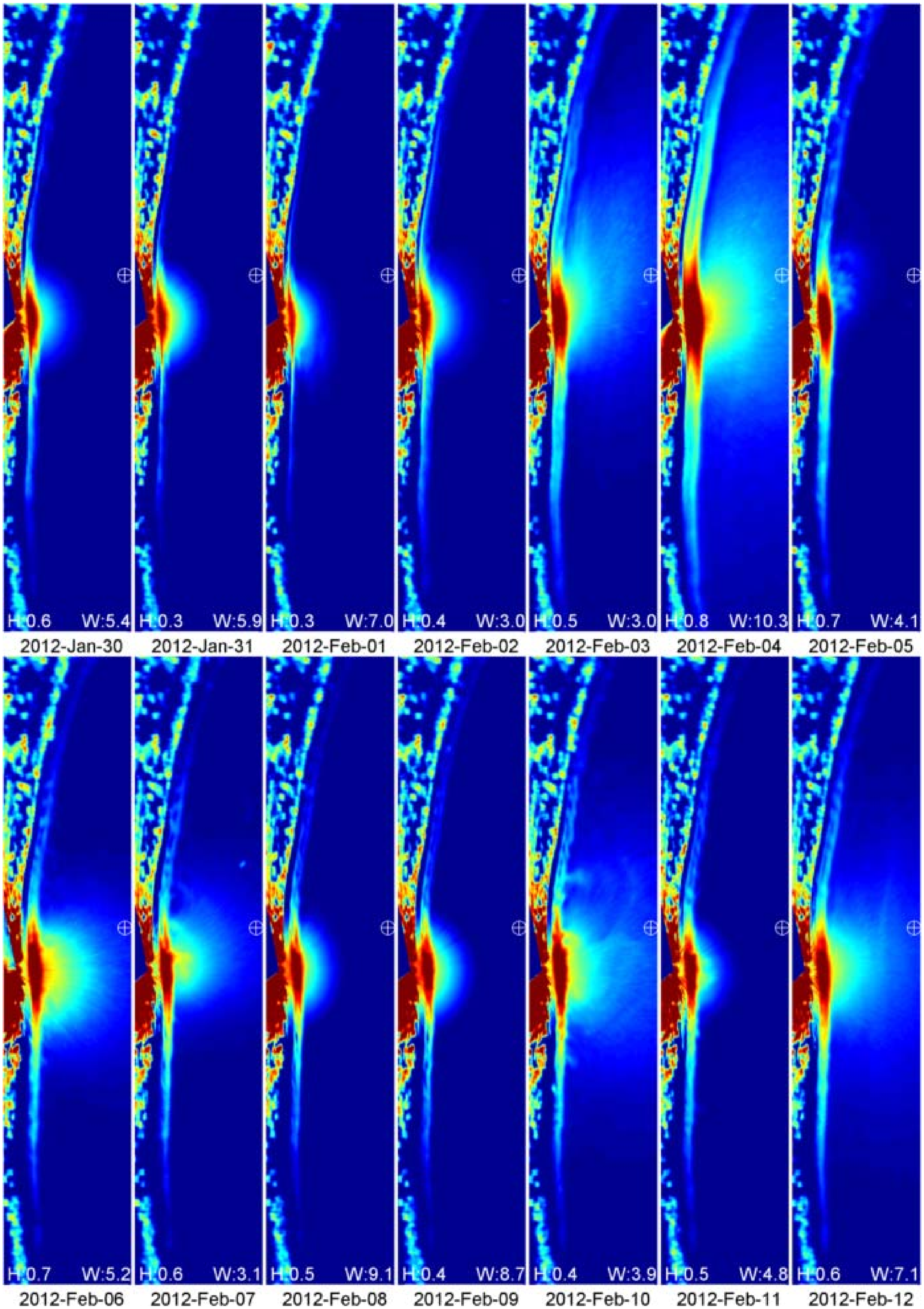
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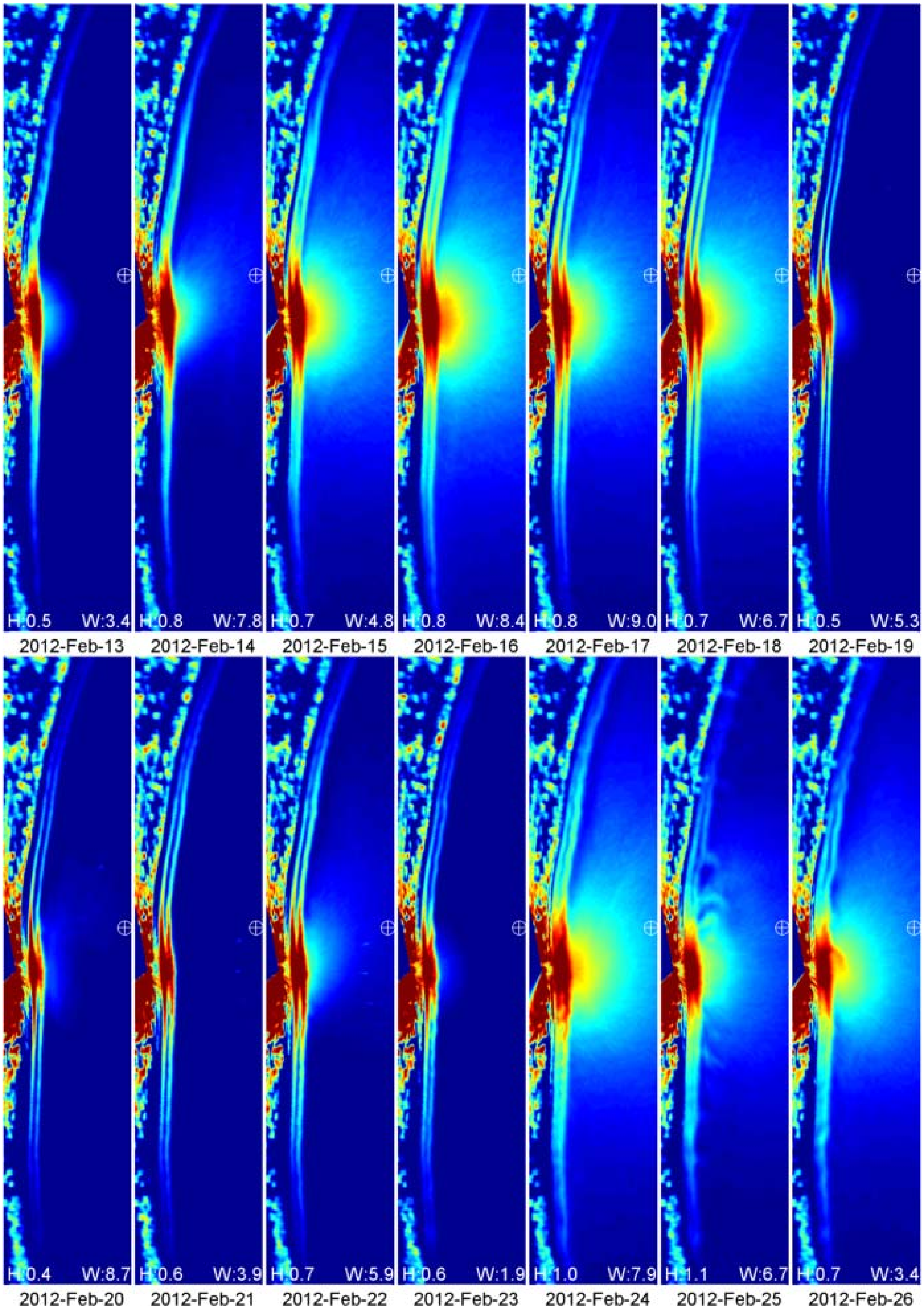
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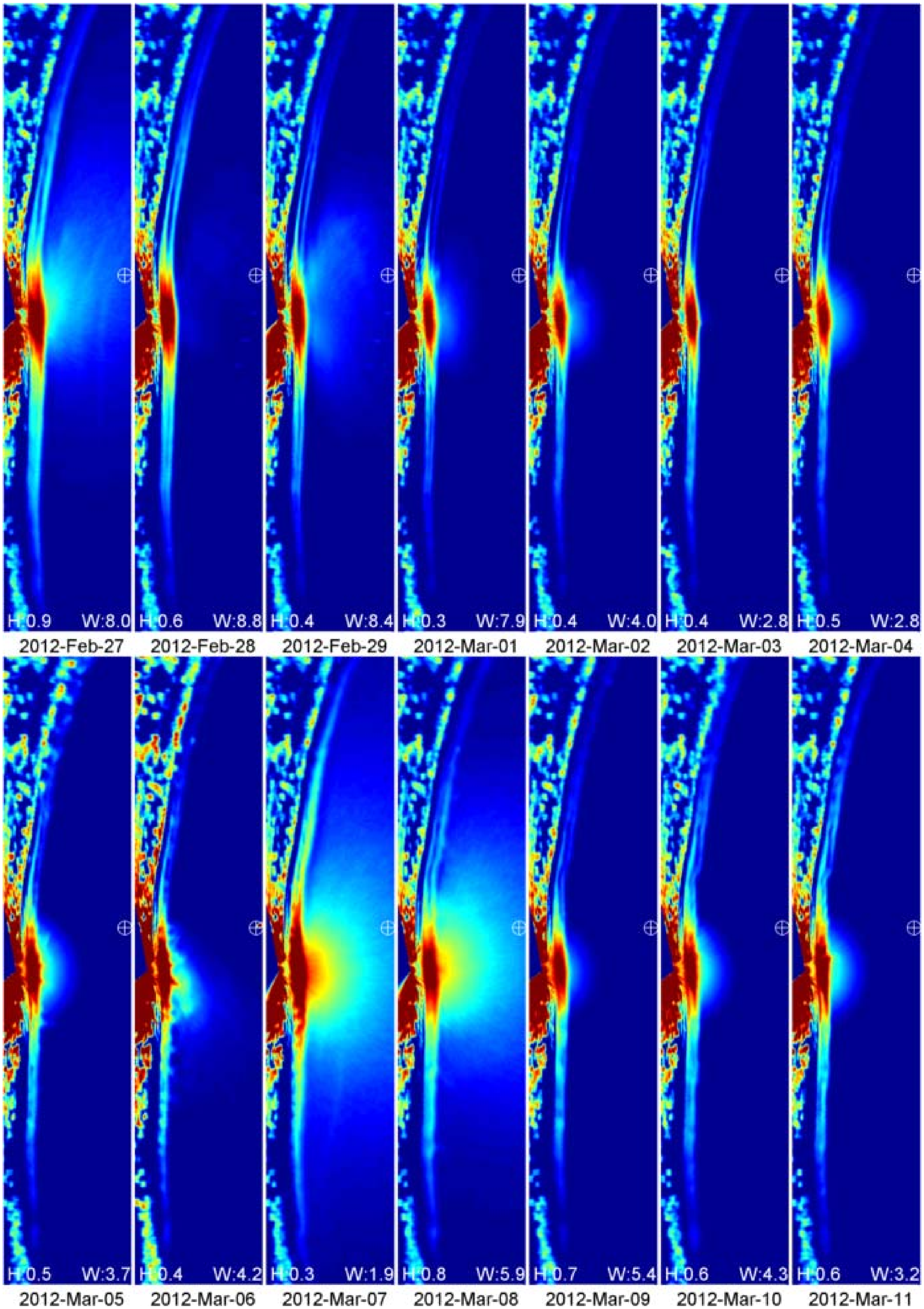
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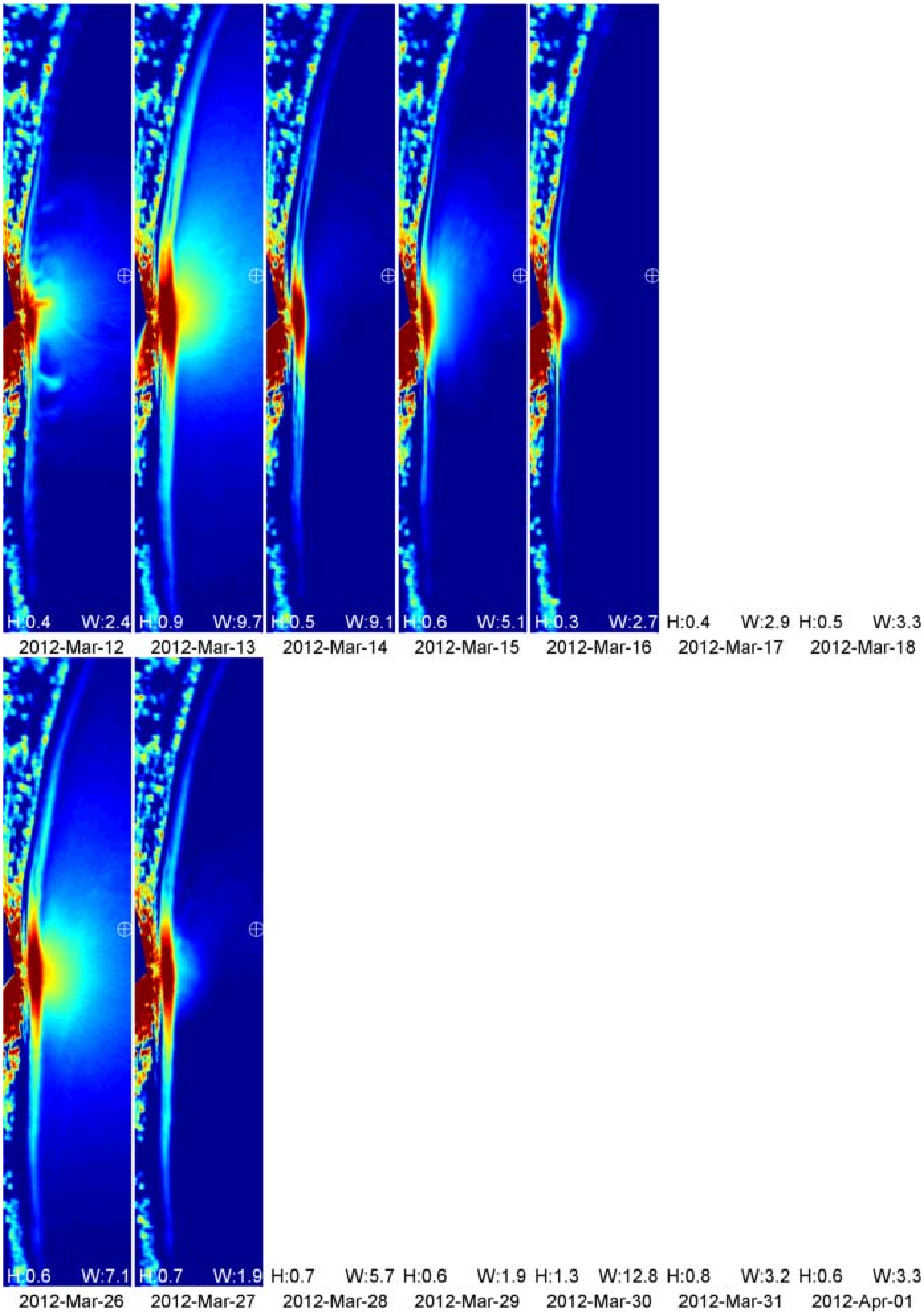

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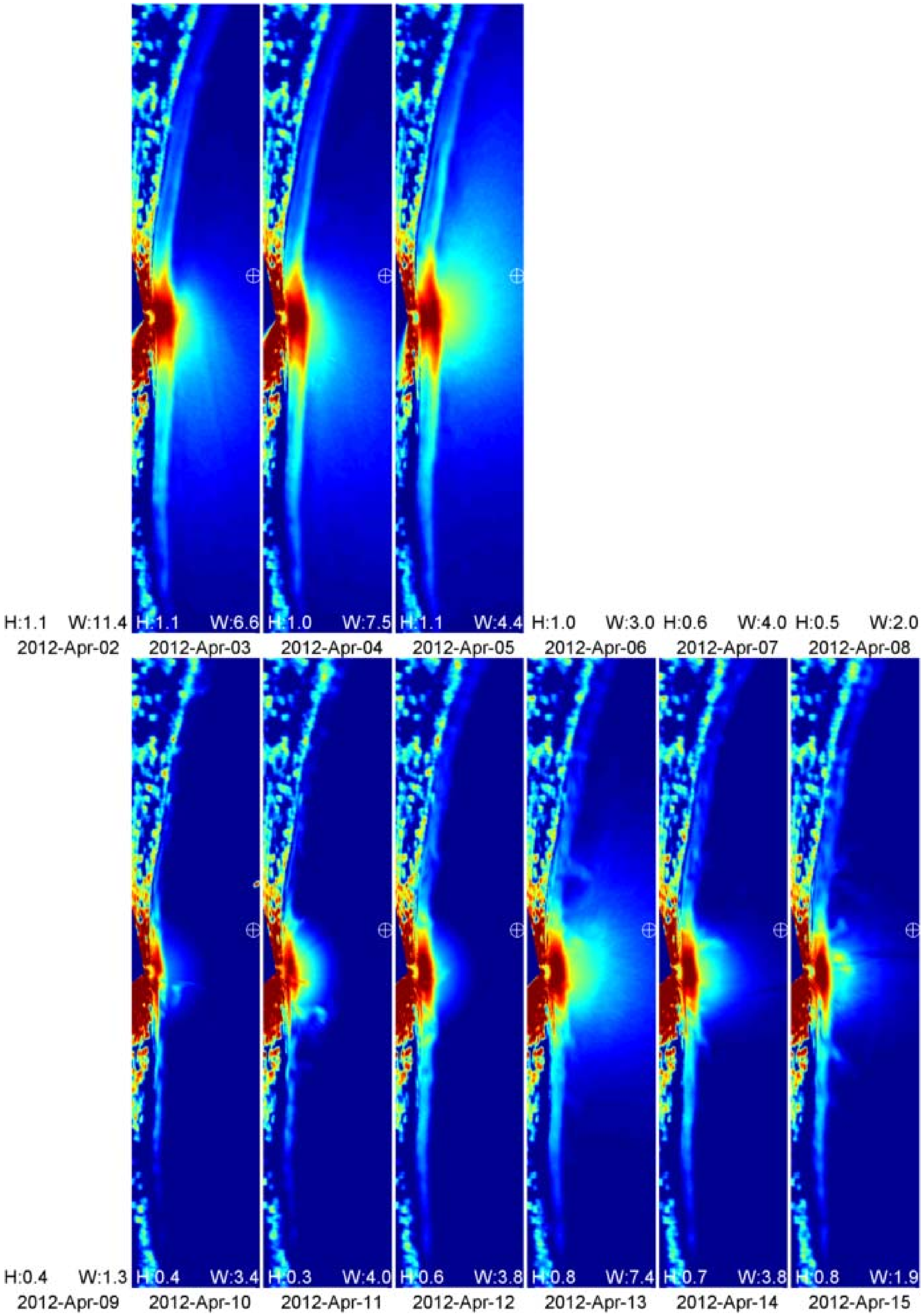
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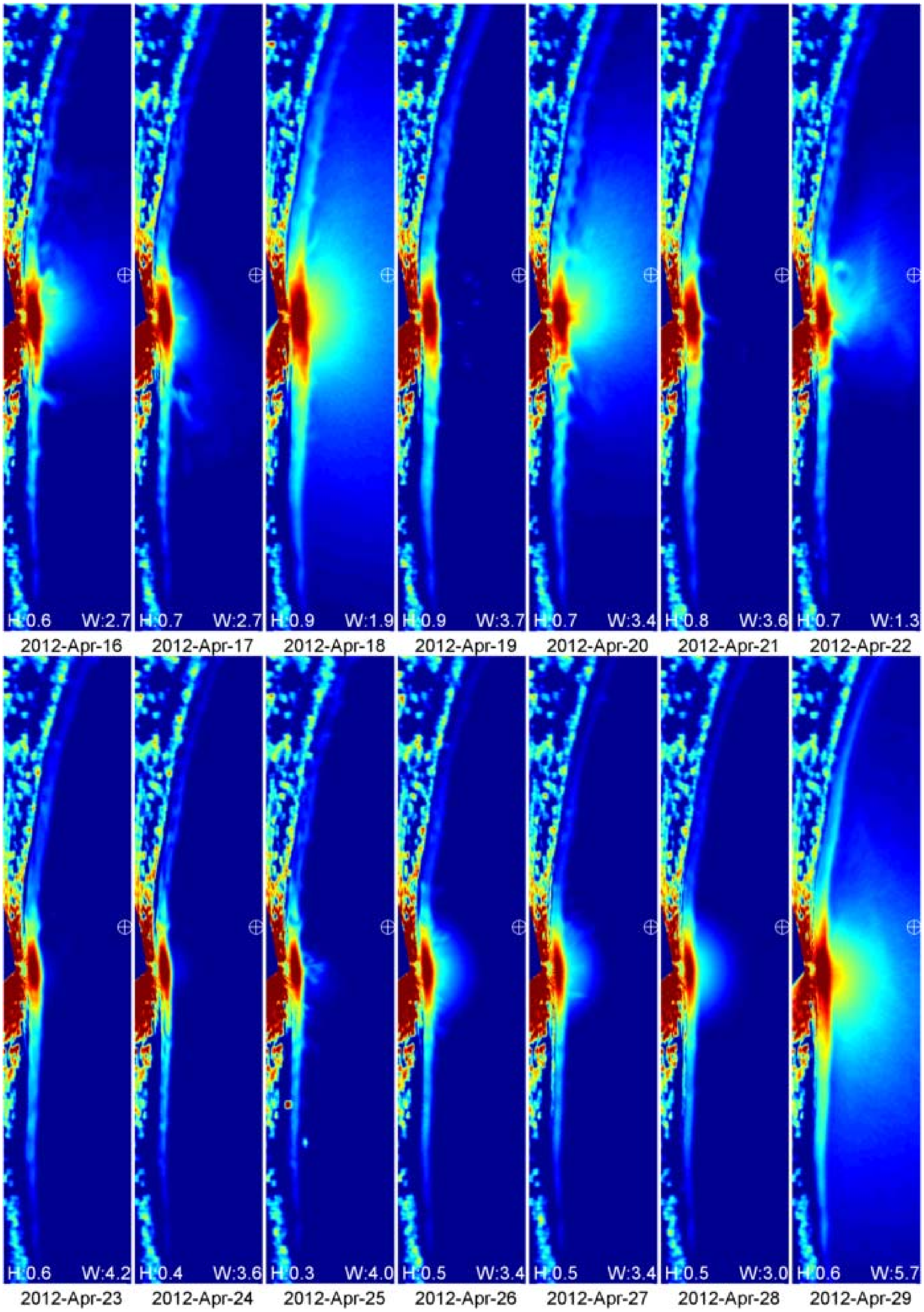
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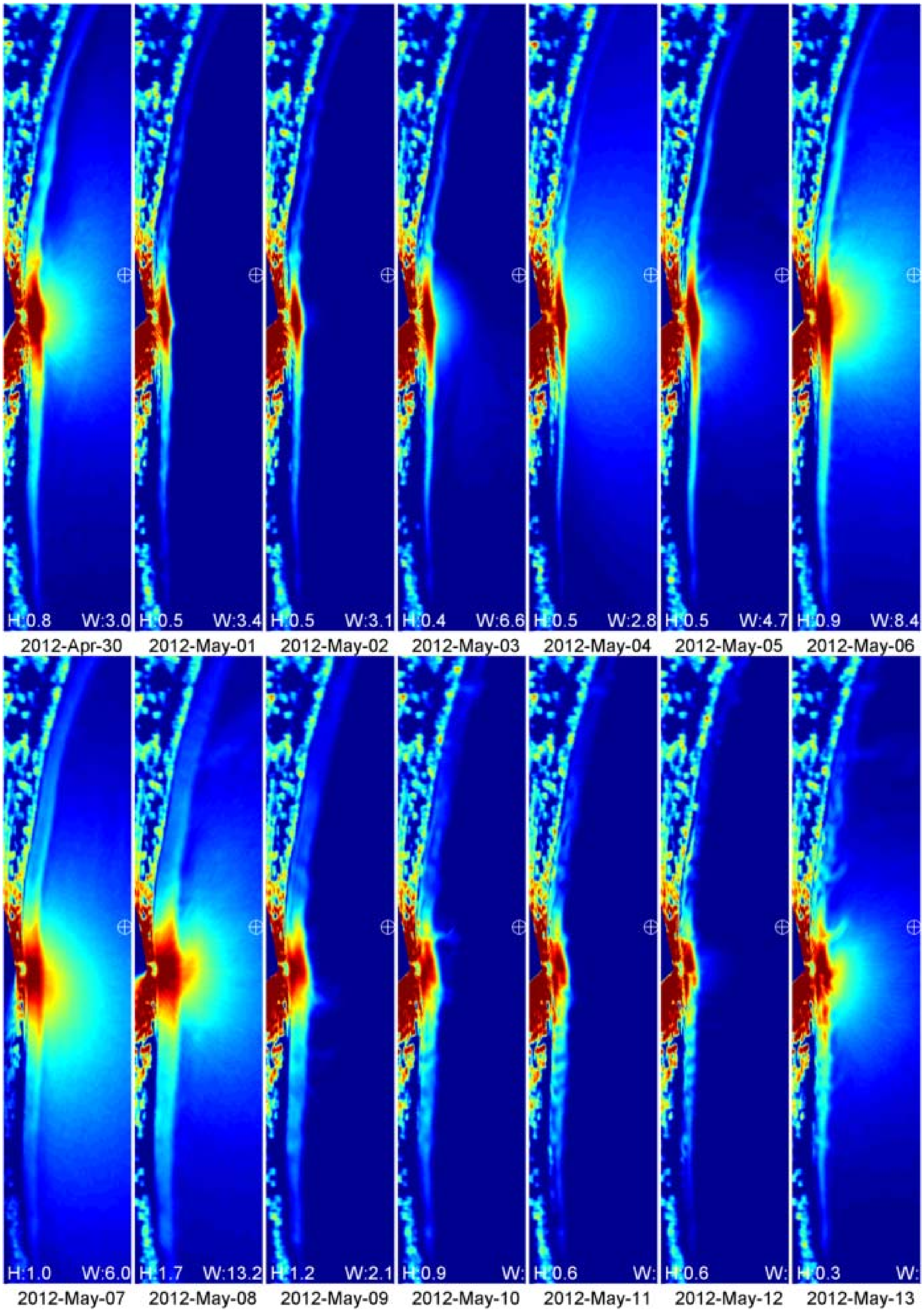
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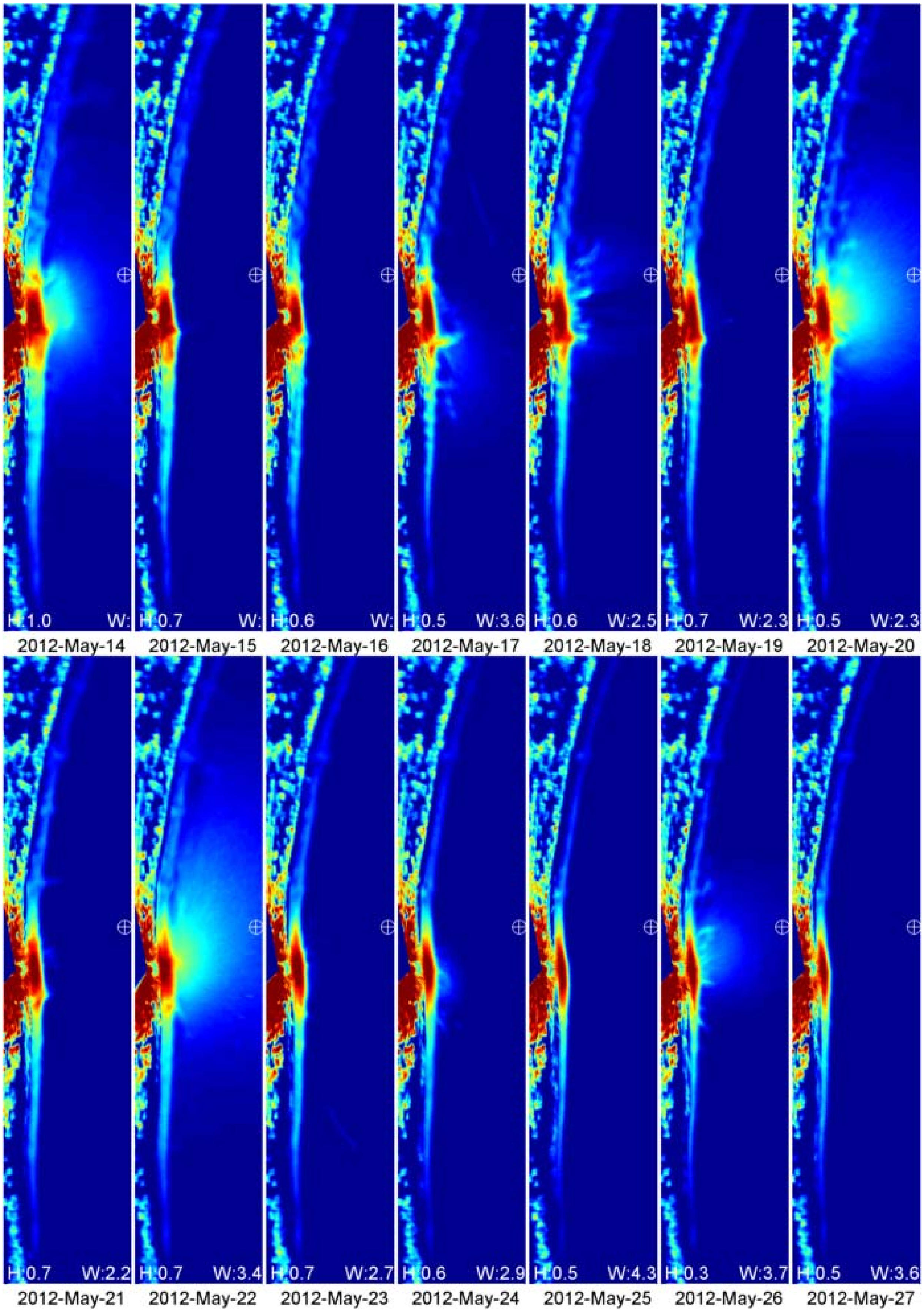
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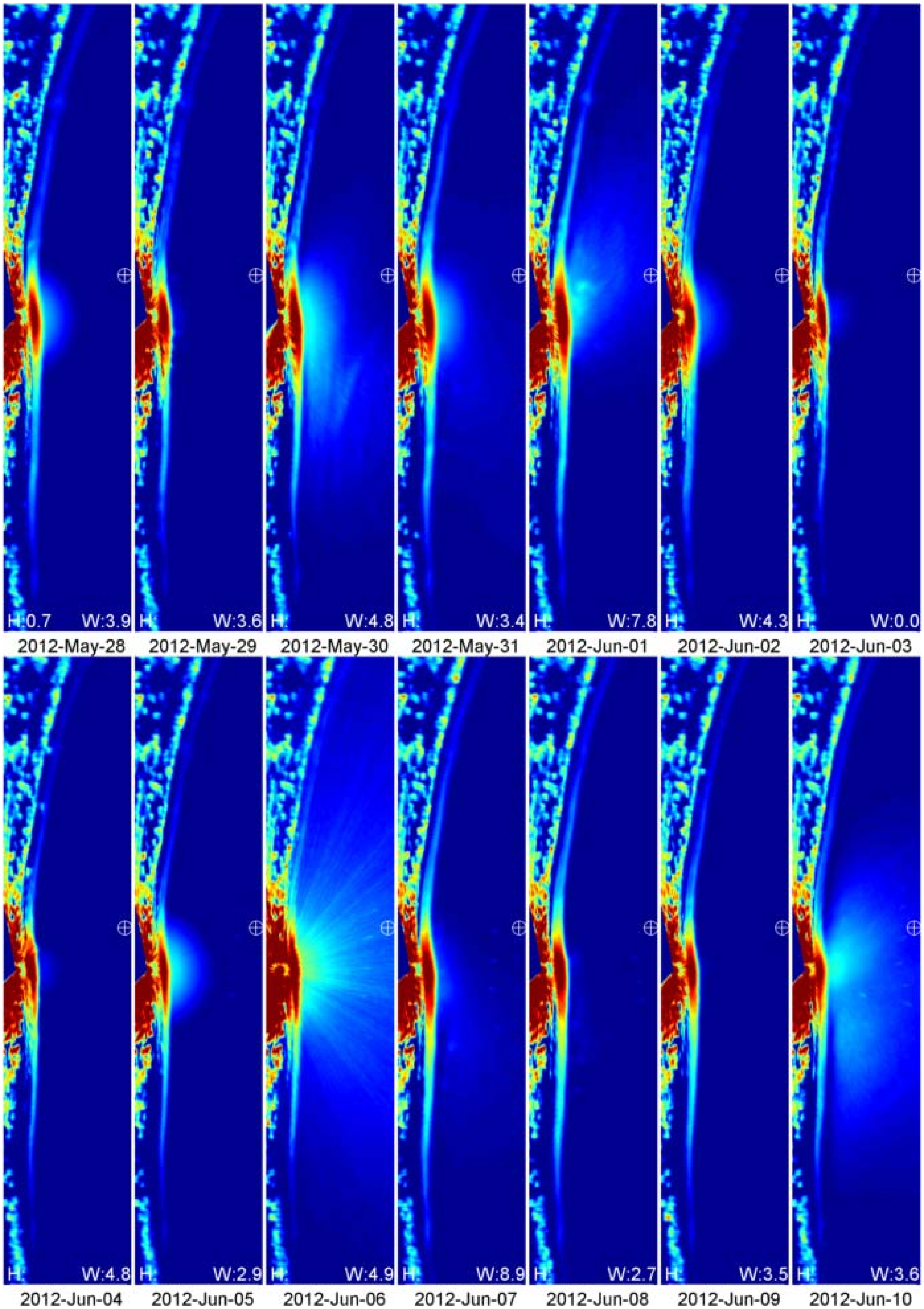
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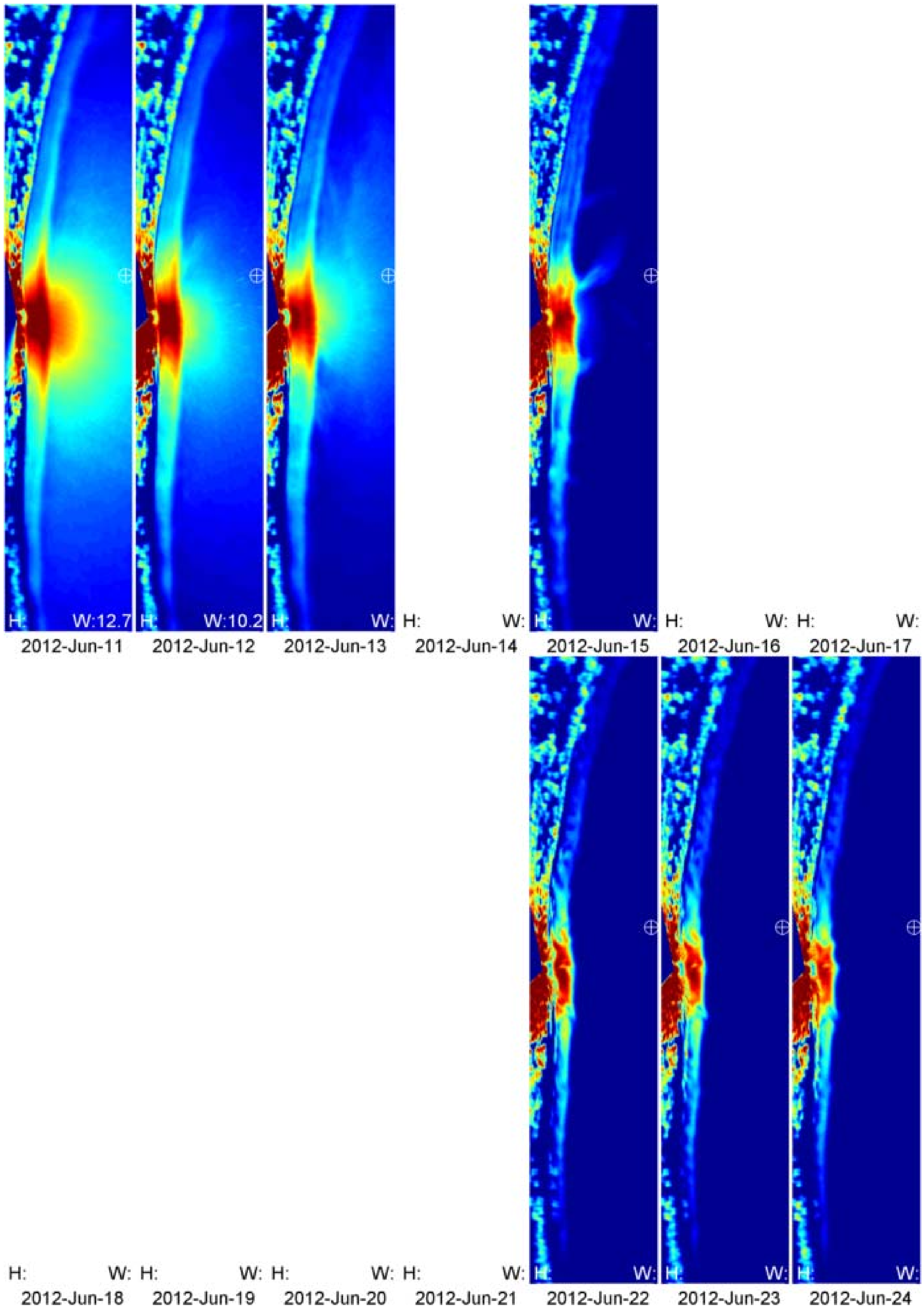
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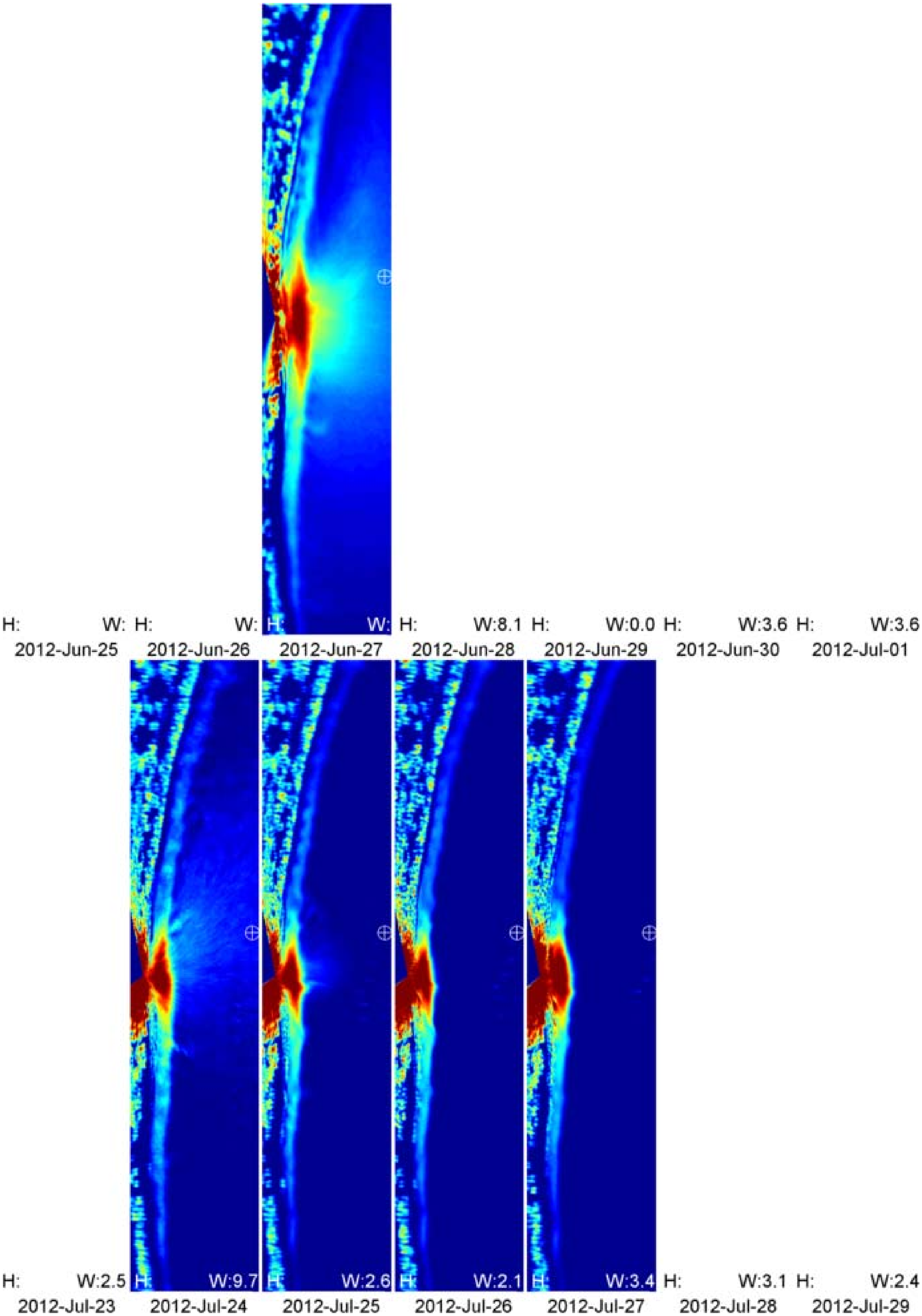
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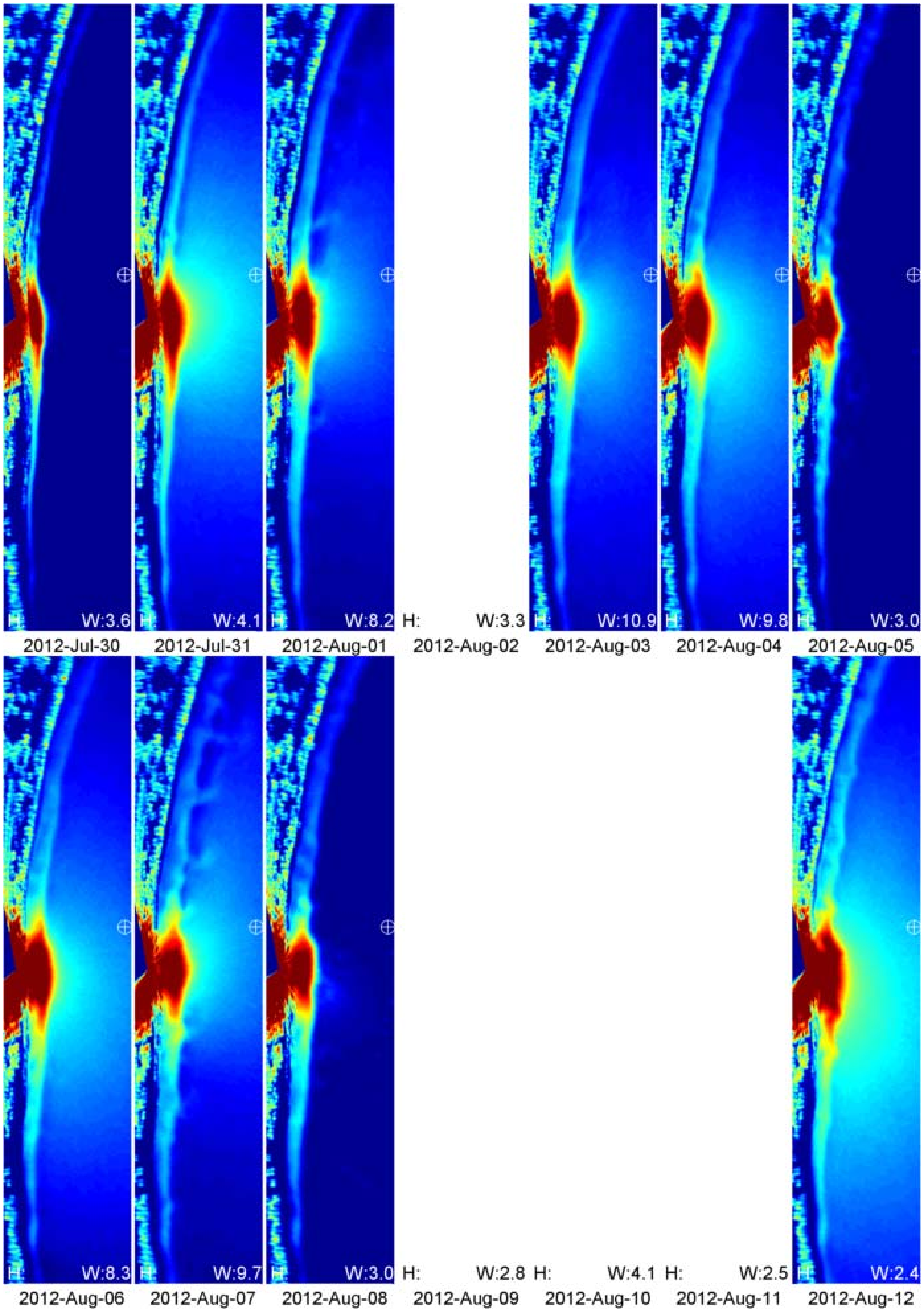
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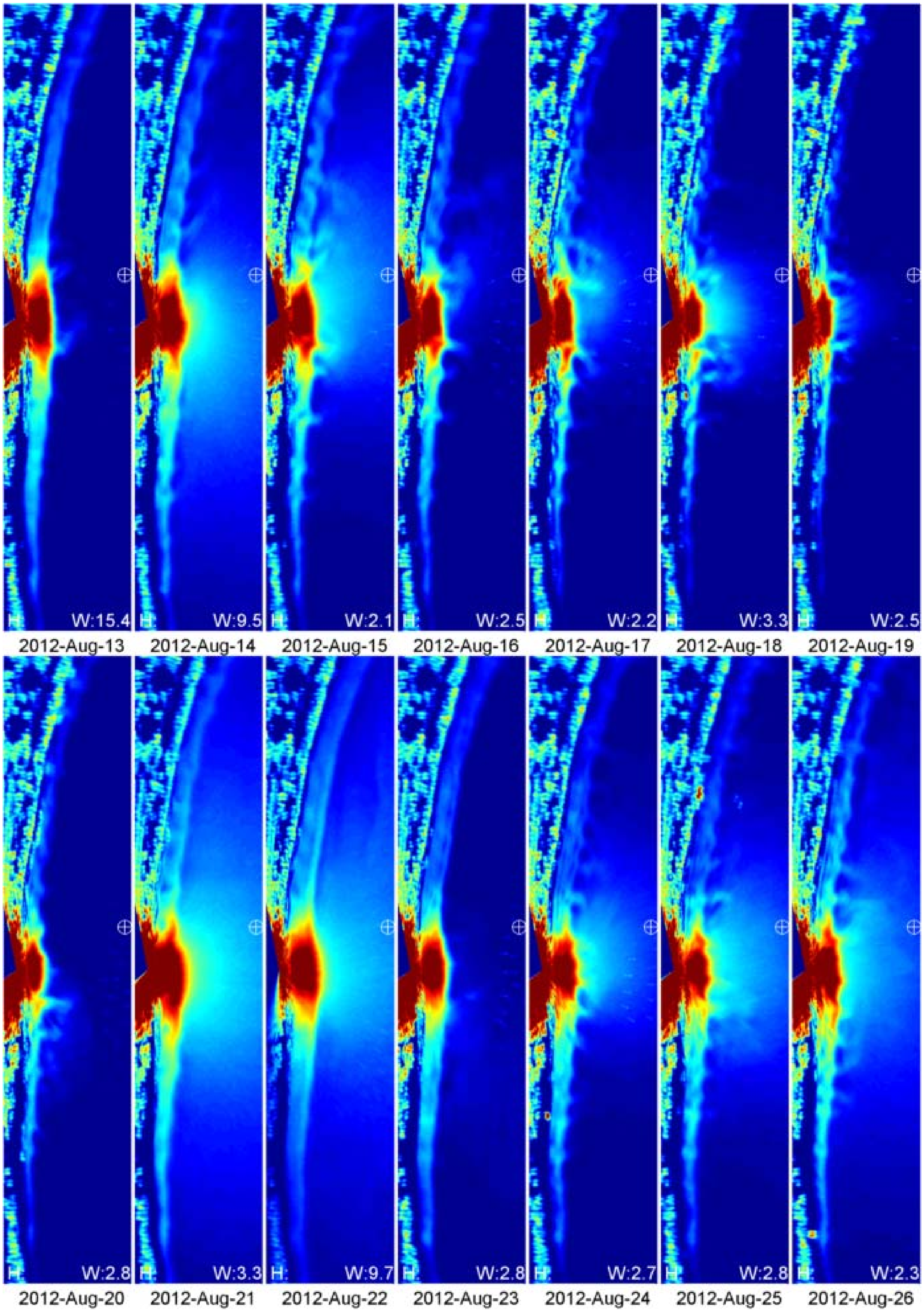
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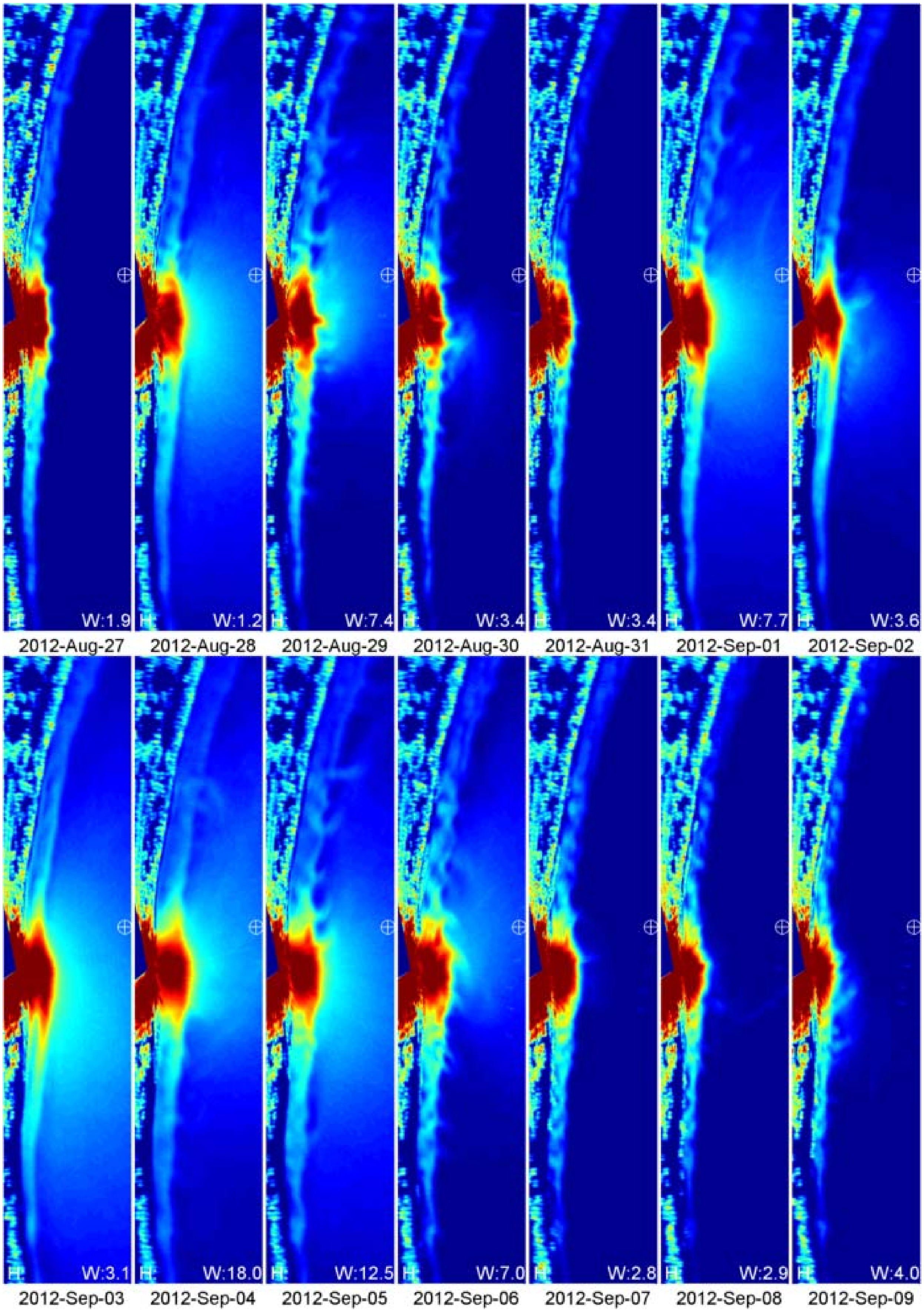
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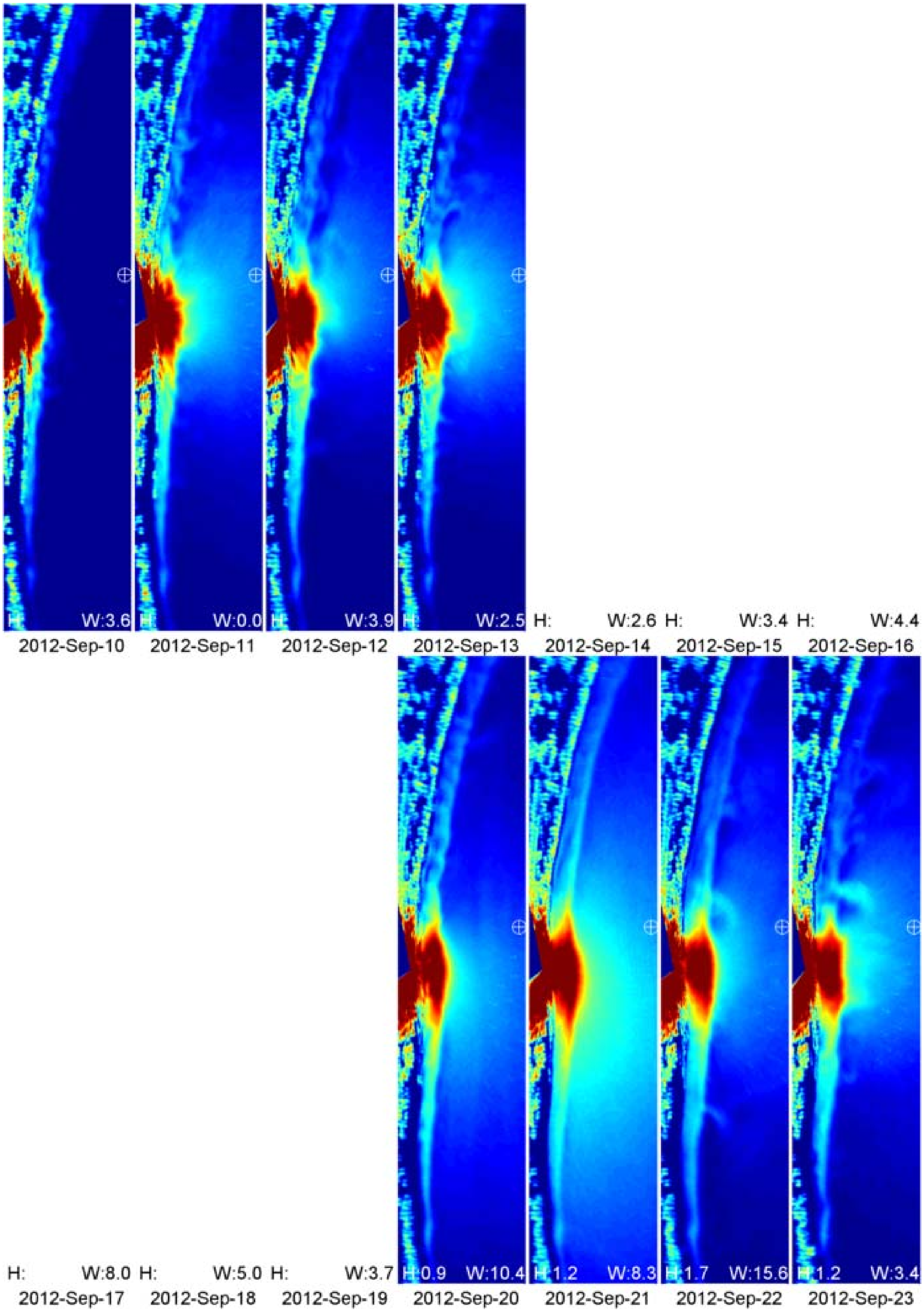
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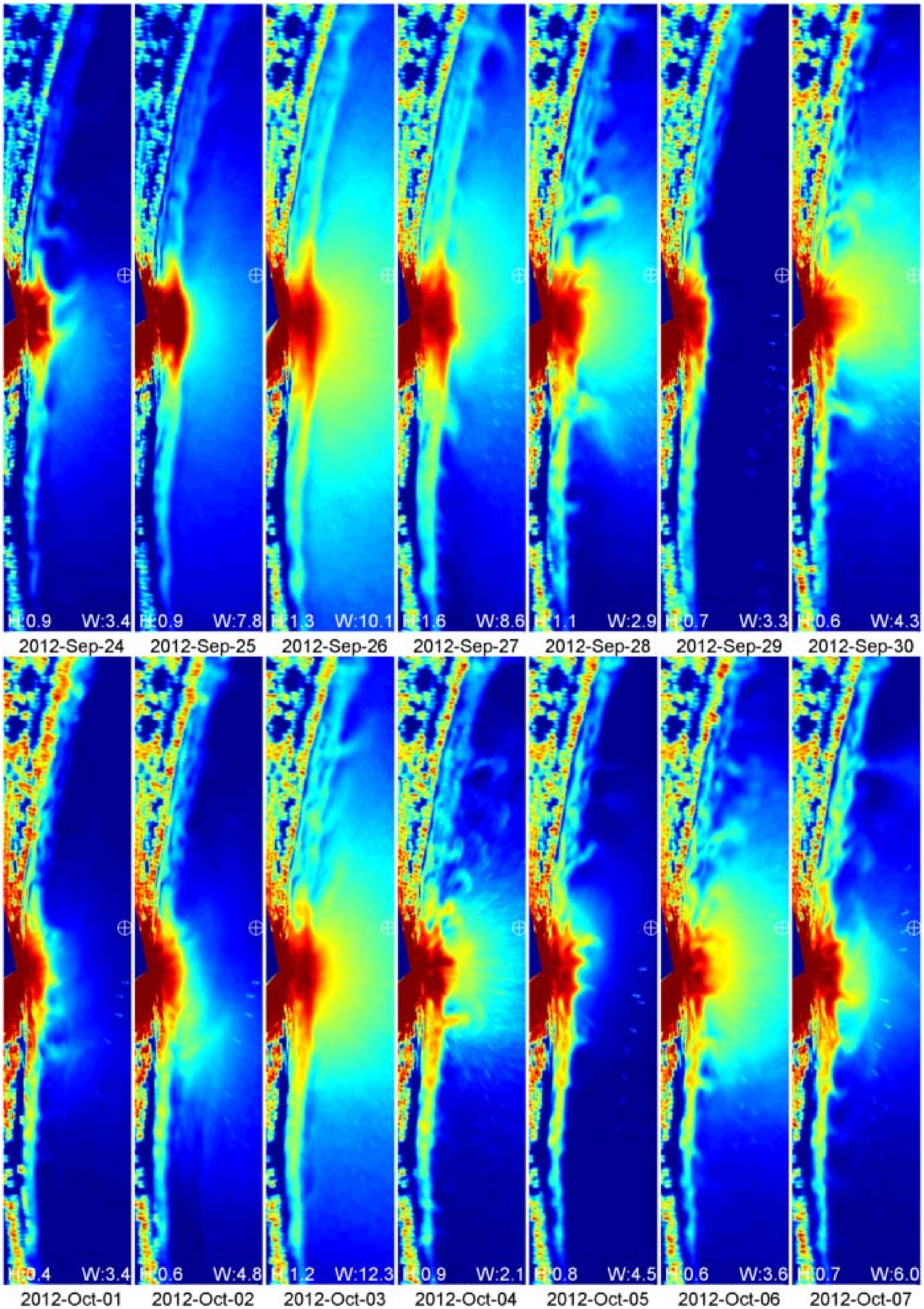
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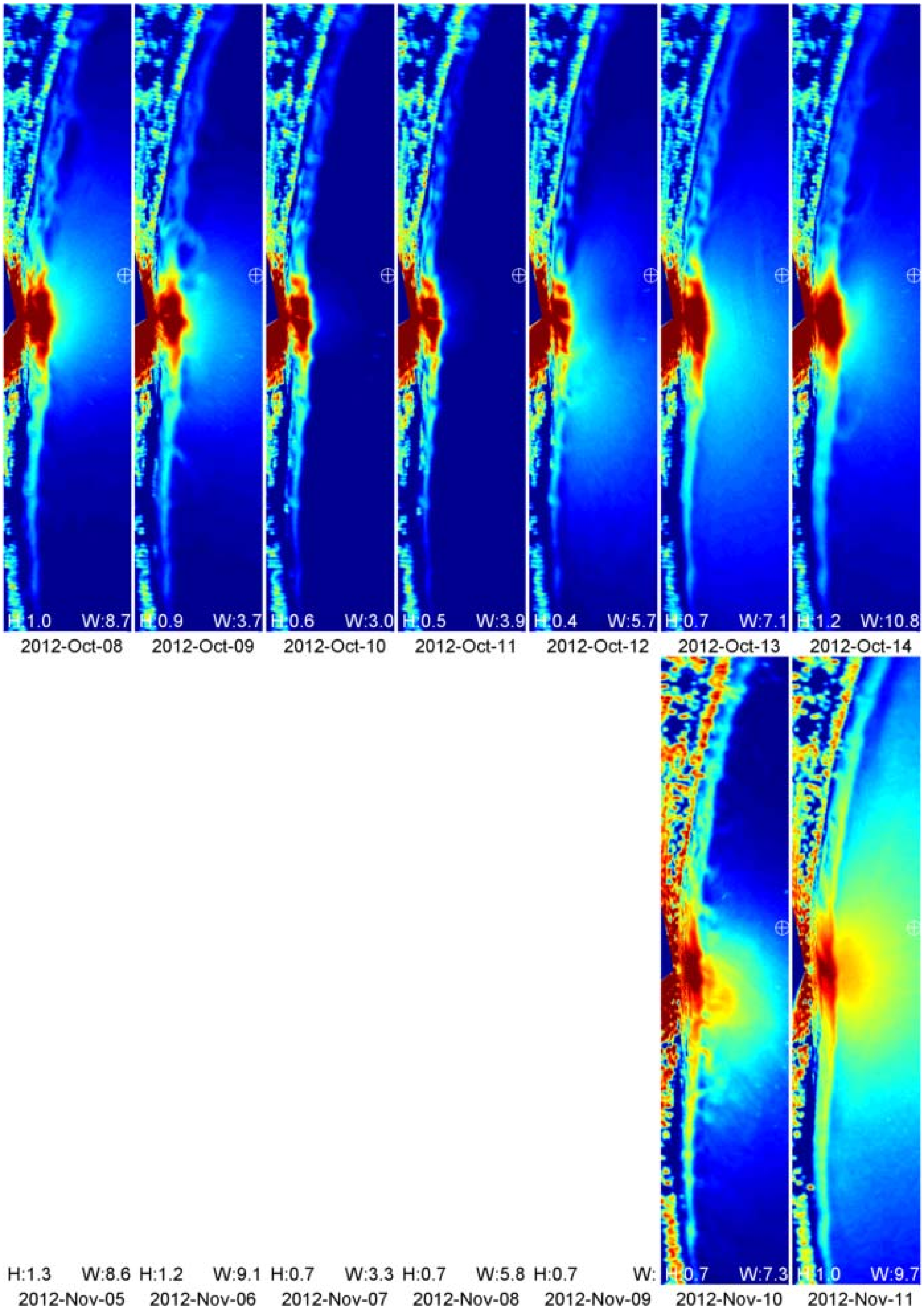
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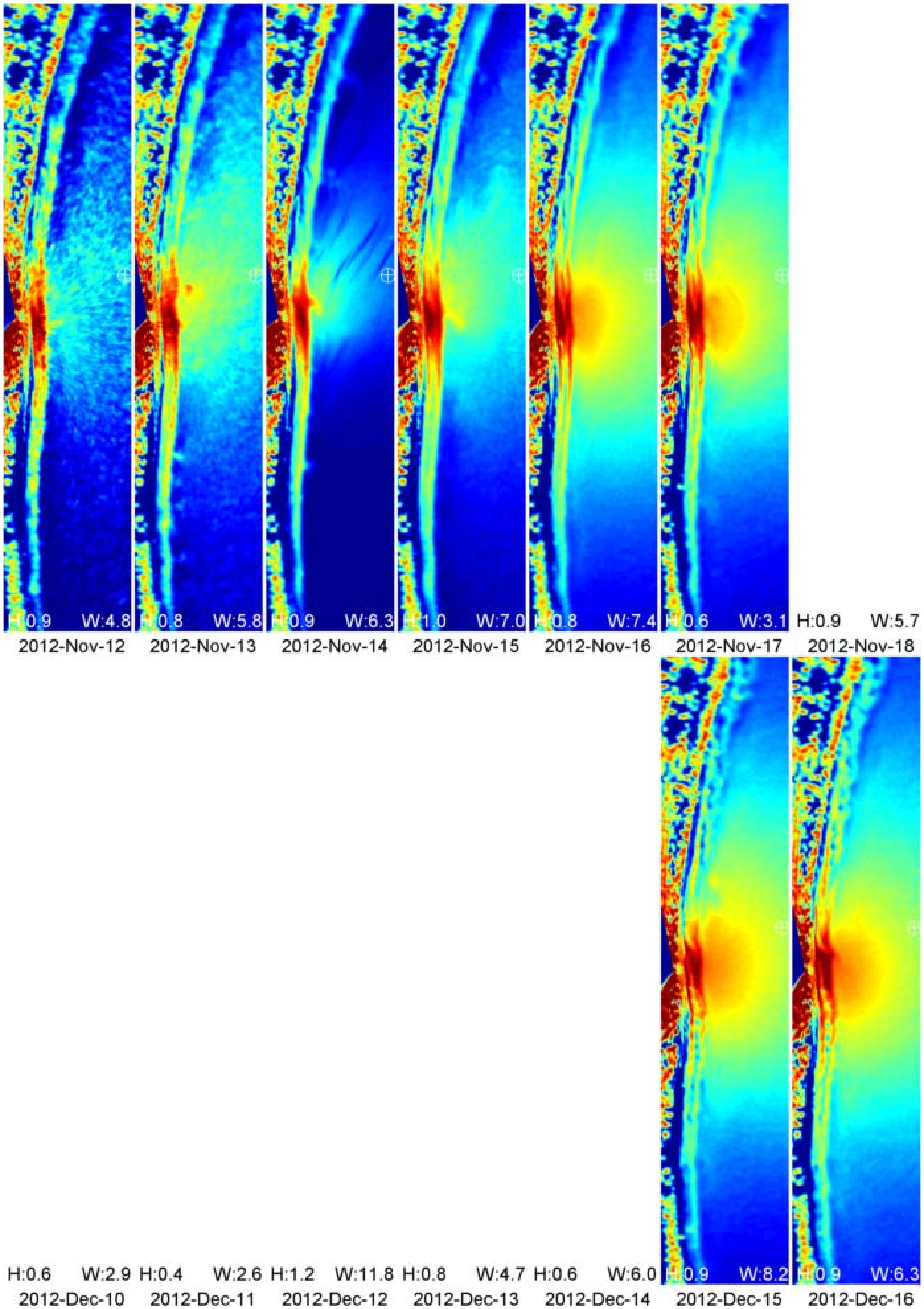
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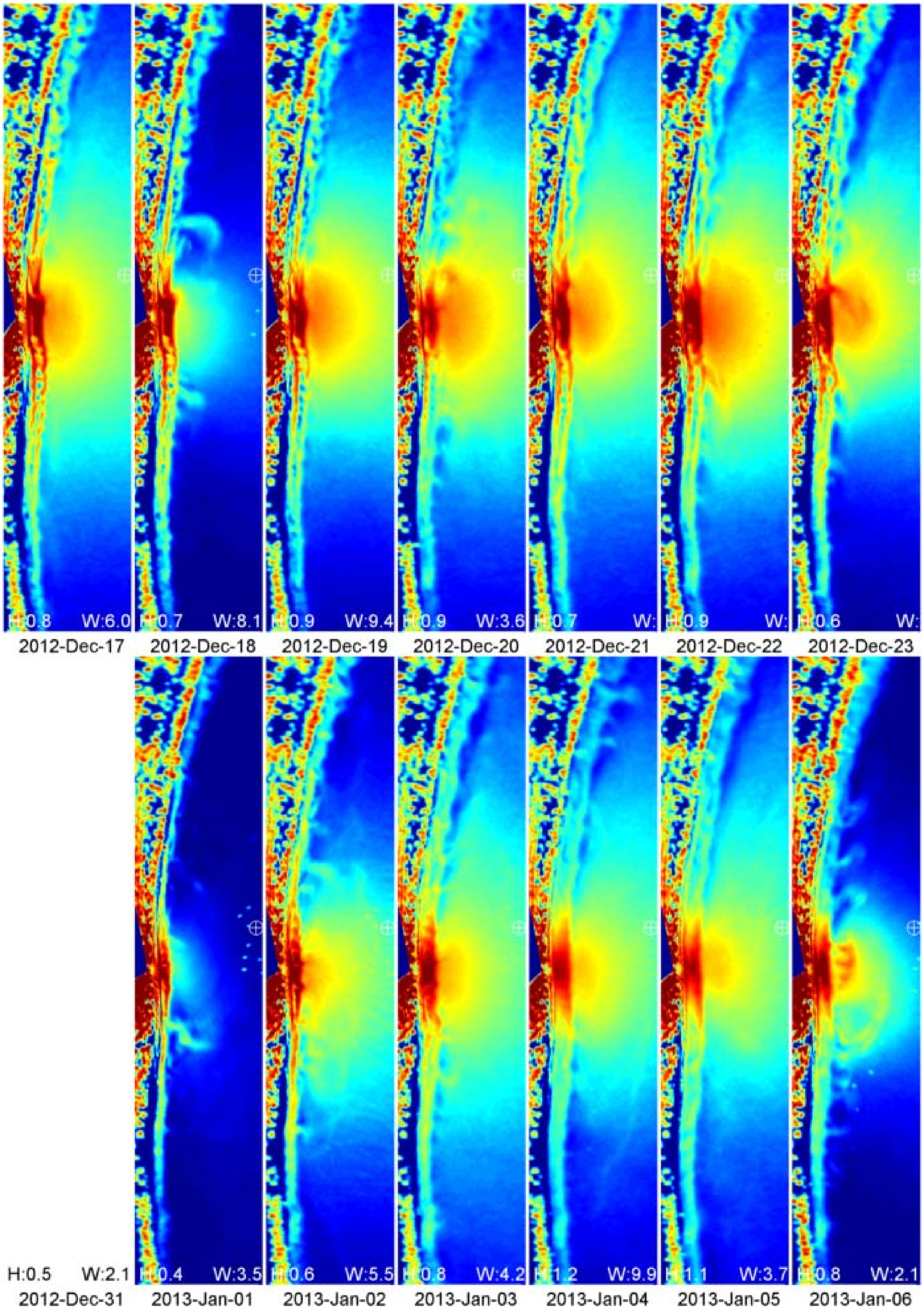
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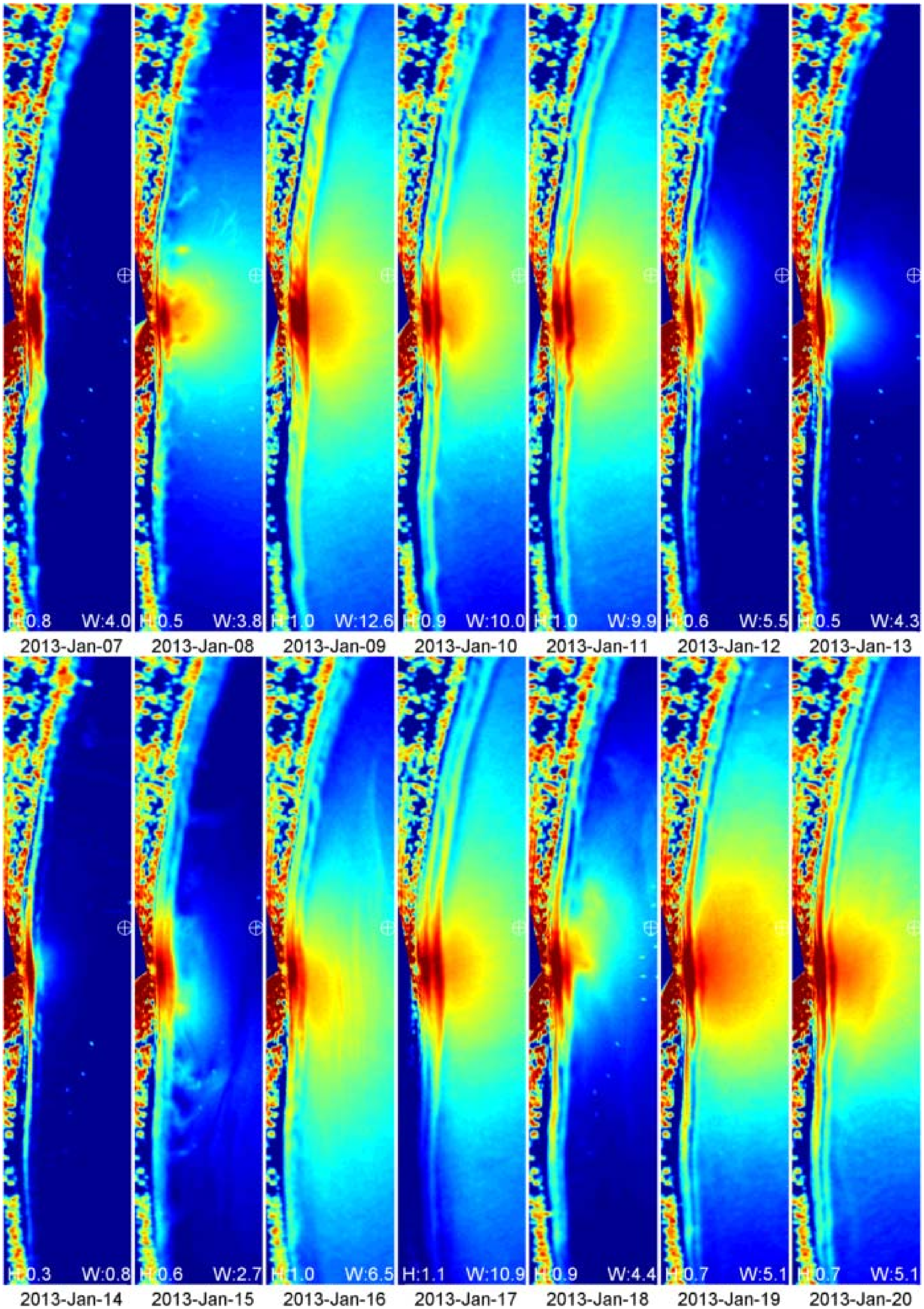
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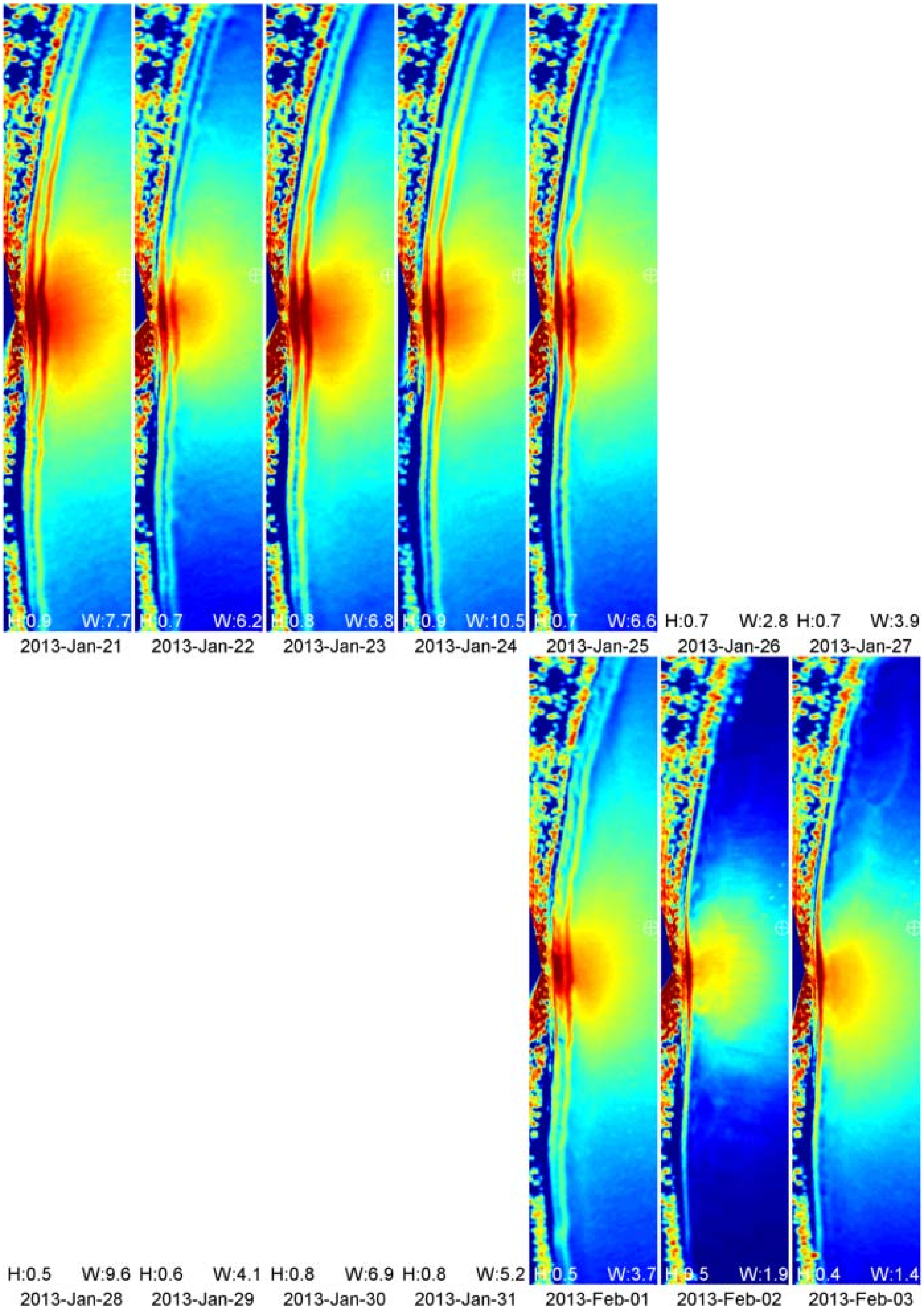
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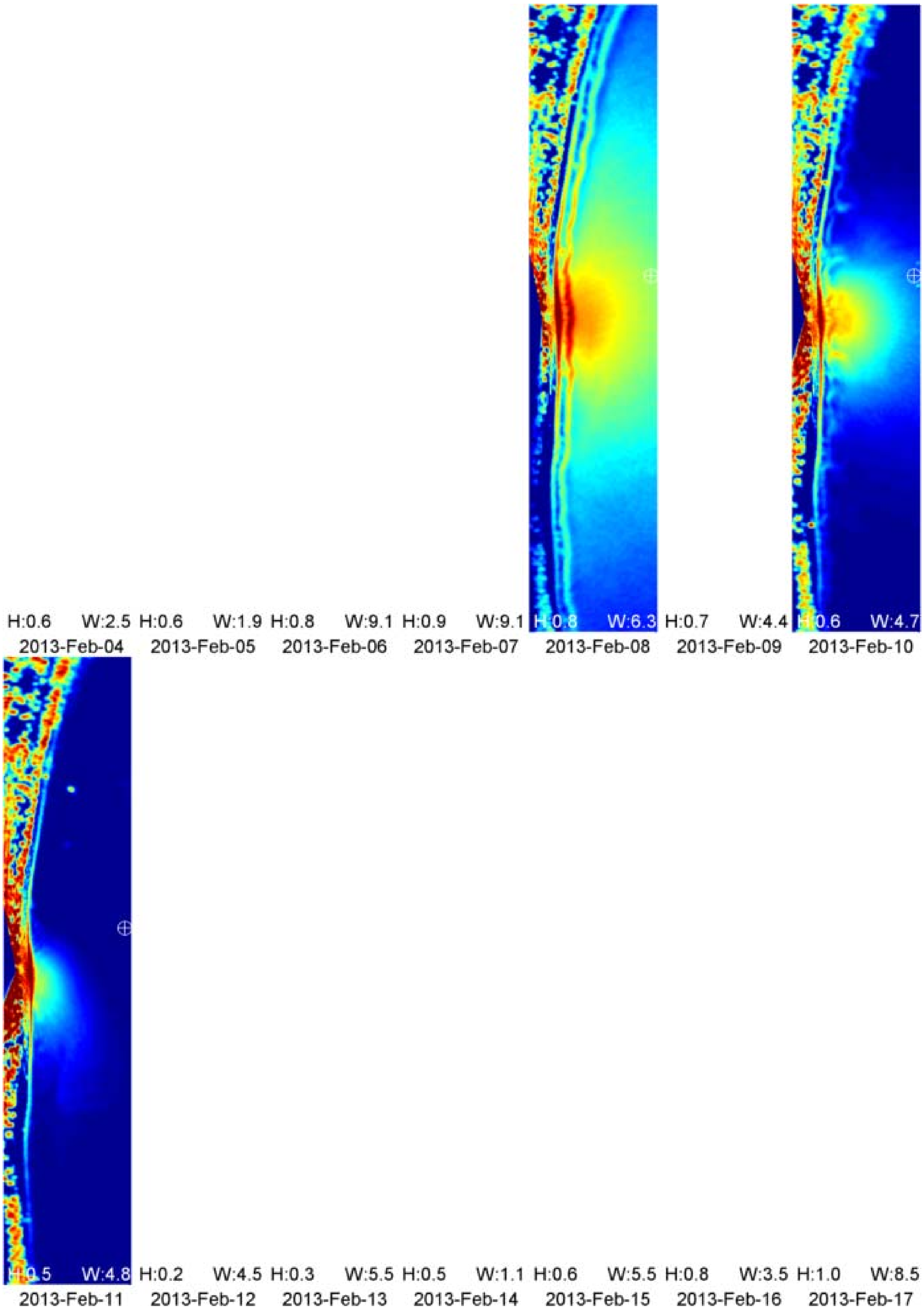
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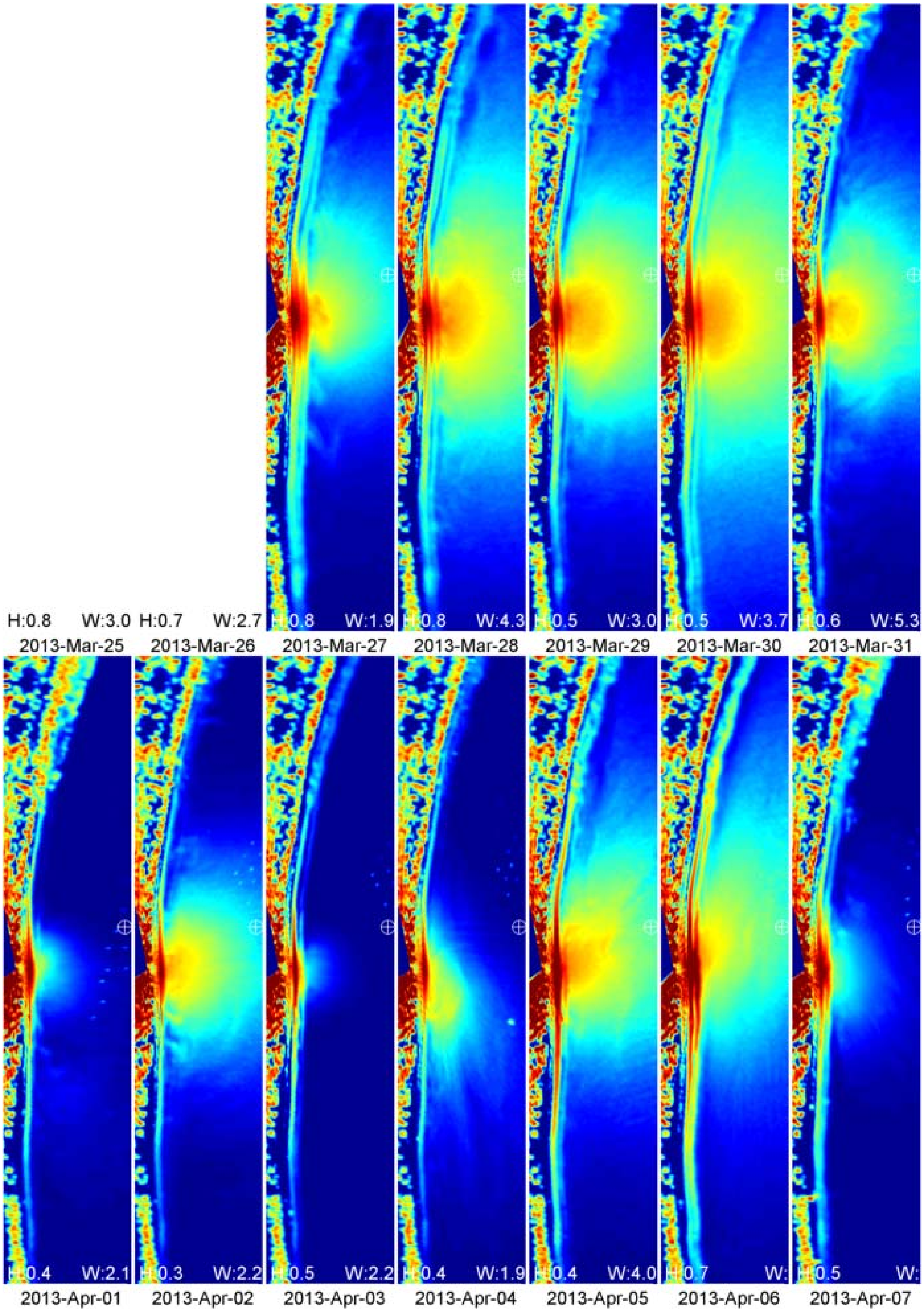
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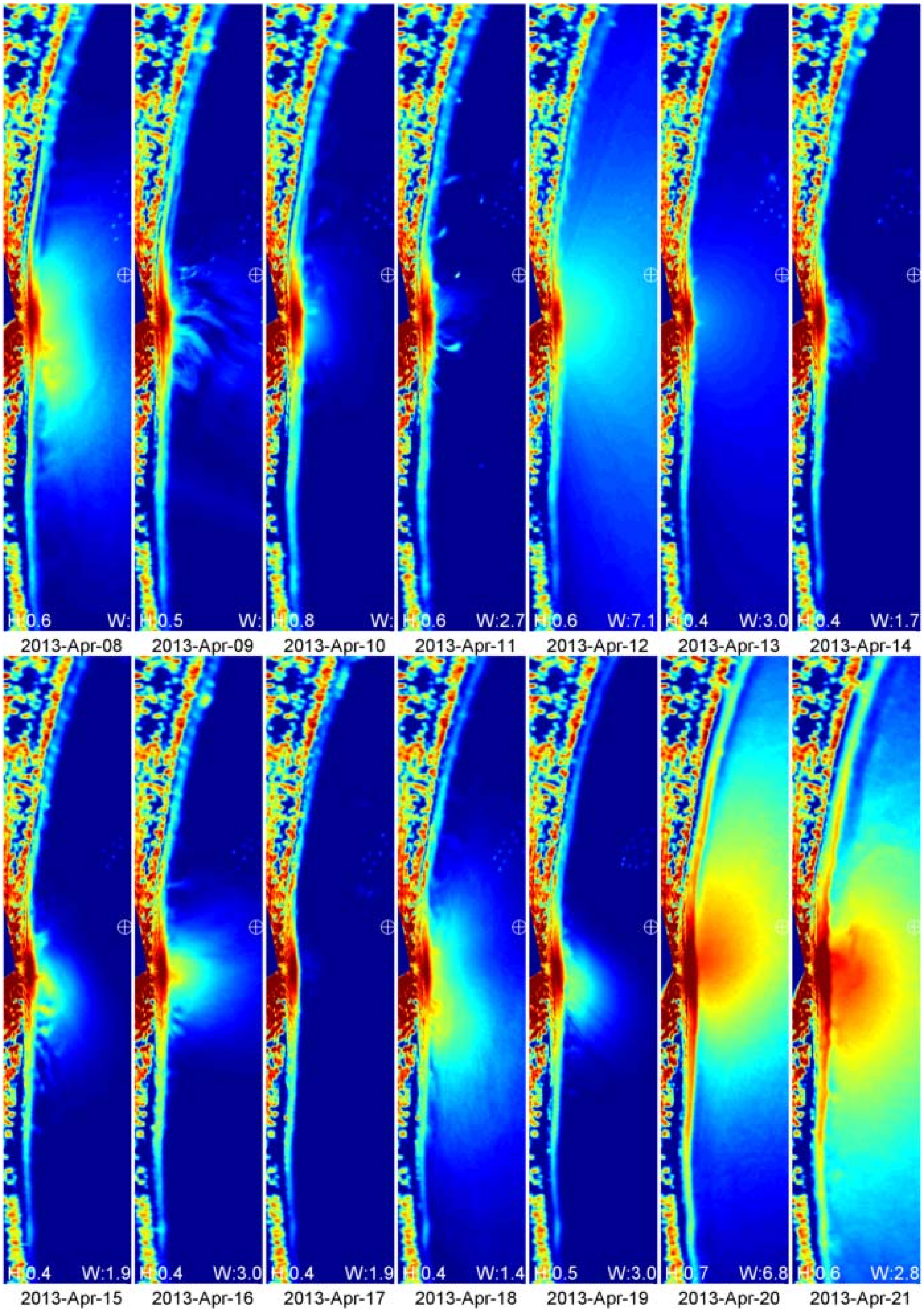
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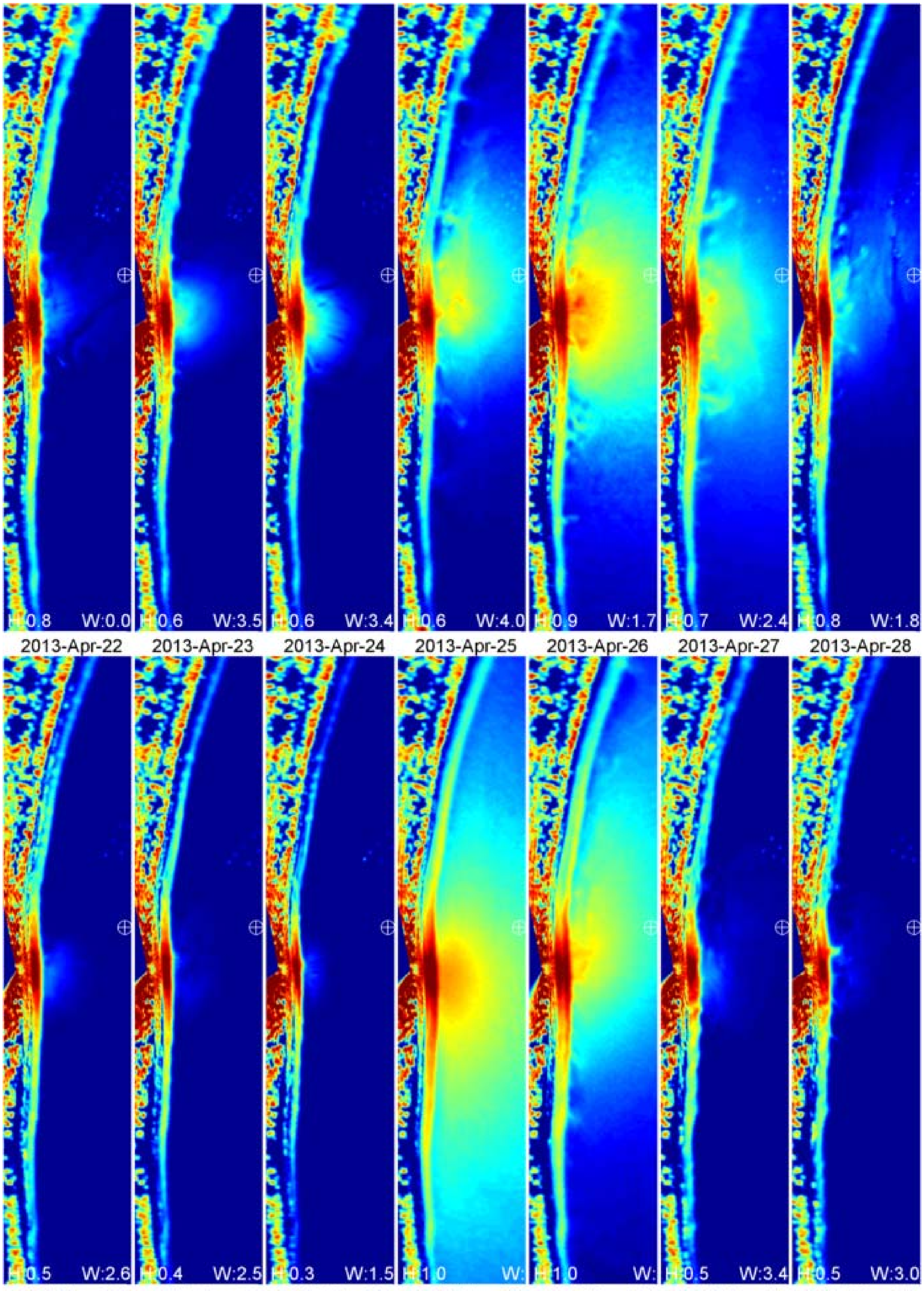
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2013-May-02
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2013-May-03
H:0.5 W:3.4
2013-May-04
H:0.5 W:3.0
2013-May-05

APPENDIX 3 SURVEY MARKS

View the graphic summary

SSM KENNEDY 4

Alternate names : R 59
Stamp name:

Map ref.: PEELHURST BG33 2.3
Physical Status : **located (Landgate)**
Phys. Status Date : 02/02/2010

Geographical Coordinates
Horizontal datum : **GDA94**
Latitude : **S 32 23 42.26878**
Longitude : **E 115 44 47.98036**

MGA Coordinates
Zone : 50
Easting (m): 382121.852
Northing (m): 6415081.085
Convergence : -0 40 17.61
Point scale factor : 0.999771350

Horizontal accuracy : 10 ppm
Horizontal method : Global Position System
Horizontal order : 2 SP1 horizontal
Positional Uncertainty (m): 0.008 (95% Confidence Level)

Cadastral connection : Exists

Project Grid - PCG94
Perth Coastal Grid 1994
Easting (m): 43413.492
Northing (m): 214338.843
Convergence : -0 2 15.02
Point scale factor : 0.999999590

Height Information
Vertical datum : **AHD71**
Height (m) : **6.261**
Vertical method : Spirit Levelling
Derived GDA94 Ellipsoidal **h**eight (m): -26.232

*** Derived GDA94 Ellipsoidal height*: **h = H + N**

Vertical accuracy : 12rootK
Vertical order : L3 SP1 spirit levelling
N-Value (m) : -32.493
Geoid Model : AUSGeoid09 V1.01
Interpolation : Bi-Cubic

The Centre for Australian Weather and Climate Research is a partnership between CSIRO and the Bureau of Meteorology.