Optimization of the parallel semi-Lagrangian scheme in the YHGSM based on the adaptive maximum wind speed

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***Abstract*—The Yin-He global spectral model (YHGSM), developed by the National University of Defense Technology, embodies a parallel semi-Lagrangian solver and has two schemes implemented: maximum wind speed and on-demand communication. The communication in the maximum wind speed uses a single, fixed data structure with a global maximum wind speed; although straightforward to implement, it incurs a high communication overhead. In contrast, the on-demand communication scheme only uses the maximum wind scheme for the wind field to calculate the trajectory. Subsequently, only necessary data are communicated for the interpolation of the other fields, which reduces the communication overhead. In this paper, a novel adaptable approach is proposed in which a monthly maximum wind speed is used in the YHGSM. The candidate monthly maximum wind speeds are extracted from the ERA-interim wind data from 2001 to 2018; the value selected corresponds to the initial date of the forecast. This approach reduces the difference between the actual wind speed and the maximum wind speed used in the model; in turn, the communication overhead in the trajectory computation is further reduced. Experiments show that in the maximum wind and on-demand schemes, the communication overheads with the adaptive maximum wind speed are significantly reduced. In addition, in a ten-day forecast with the on-demand communication scheme, the total overhead for the semi-Lagrangian computing and the total parallel execution time are also both reduced, and the reduction ratio increases as the number of nodes increases.**

Keywords*—numerical weather prediction, parallel Semi-Lagrangian scheme, maximum wind speed, communication overhead

I. INTRODUCTION

The atmospheric transmission process is very important in modelling and predicting atmospheric movements. The process is mainly characterized by an advection scheme, which influences the performance of the numerical forecast model [1]. Therefore, improving the stability and accuracy of this scheme is vital. In the model integration, a long-standing problem is that the maximum time step is limited by the Courant-Friedrichs-Lewy (CFL) condition [2], and this effect is greater than the consideration of its accuracy. To keep the integral stable, the time step must be small enough so that the time truncation error is much smaller than the space truncation error. Early numerical weather prediction (NWP) models used an explicit leapfrog format, and their time steps were limited by the high-frequency fast waves. Implicitly processing these fast wave terms can increase the time step size to a certain extent, but this step is still very small compared to considering only the accuracy requirements. In order to break the limitation of CFL conditions, we need to introduce an integration method with the same accuracy and saving machine time.

Proposals to address this limitation include the semi-Lagrangian scheme [3]; although a larger time step can be used, the scheme has not obtained widespread adoption due to its complicate nature and modest performance improvements. The semi-Lagrangian scheme has gradually matured as meteorologists continue to study this problem of extending the time step and shortening the calculation volume in each step in it. Among them, extending the time step can be achieved by establishing unconditional stability, and shortening the calculation volume in each step is achieved by constructing a differential format for calculation replacement. However, the physical quantity calculated by interpolation lacks conservation in the semi-Lagrangian advection scheme, thus bringing systematic errors to long-term numerical integration [3]. To this end, many scholars are devoted to constructing the difference scheme under conservation conditions [4]. In the early 1970s,

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the Chinese scholar Q. C. Zeng first proposed a semi-implicit scheme [5]. In the same equation, the terms that excite fast waves are expressed implicitly, and the terms that describe slow waves are expressed explicitly. Shortly after this, Robert has proposed a hybrid model, the semi-implicit semi-Lagrangian scheme based on three-time levels [6]. This scheme further increases the maximum time step and obtains the same time truncation error as the space. Over time, the semi-Lagrangian scheme has grown in popularity in numerical forecast models [7]; it has been often used in conjunction with the semi-implicit integration schemes [8].

With the development of high-performance computers, parallelization has become one of the main directions for model optimization, including the proposals of parallel semi-Lagrangian schemes [9]. The European Centre for Medium-Range Weather Forecasts (ECMWF) has introduced the maximum wind scheme [10] and the on-demand communication scheme [11] for the semi-Lagrangian calculation in the IFS. The on-demand communication scheme communicates according to the actual needs for the interpolation when communicating outside the wind field, avoiding a fixed communication pattern in the maximum wind scheme [12], thereby reducing communication overhead. However, the on-demand communication scheme must be implemented based on the wind filed, and the communication for the wind filed itself must be based on the maximum wind scheme, and there is still a large additional communication overhead.

In this paper, the concept of an adaptive maximum wind speed is proposed, to address the problem of the global maximum wind speed overestimation. Rather than a single global maximum wind speed value, the largest wind speeds that have appeared in the history of each month are obtained by a statistical analysis of the ERA-interim wind field from 2001 to 2018. From these values, the maximum wind speed that is utilized changes according to the initial time for the desired forecast. The adapted maximum wind speed value reduces the unnecessary communication overhead caused by an overestimated global maximum wind speed.

II. Limitations of the Parallel Semi-Lagrangian Scheme in the YHGSM

Model equations based on shallow atmospheric and static equilibrium approximations are used in the YHGSM, and the temperature, wind, specific humidity, and logarithm of the ground pressure are used as the dependent variables. A two-time-level semi-implicit semi-Lagrange scheme is used for integration with the time step of 720 seconds. In the vertical direction, a finite element discretization based on a cubic spline interpolation and terrain following pressure-based coordinates are used. There are 91 vertical layers in all. In the horizontal direction, the spherical harmonic spectrum expansion based on a trigonometric truncation is used in the spectral space, where the maximum truncated wave number is 799; a linear Gaussian reduced mesh is used in the grid space. A parallel computation framework similar to the IFS [11] is adopted in the YHGSM, which is based on three-dimensional array transpositions. The framework performs a domain decomposition in the horizontal direction for the grid space, and it performs a domain decomposition in the vertical and the meridional directions for the Fourier space. The spectral space is decomposed in the direction of two wave numbers, and the resulting arrays are redistributed through the three-dimensional array transposition between different spaces. This adapts the local domain decompositions for the corresponding spaces [13].

A. The Communication for the Halo Domain Based On The Global Maximum Wind Speed

In YHGSM, the communication for the halo domain is similar to the IFS [11]. In the semi-Lagrangian scheme, after performing the domain decomposition strategy on the calculated physical quantities, the tasks are assigned to different processors, and each processor processes a subset of the data. When performing calculations, those processes with requirements must be able to obtain data for all grid points in the element template. For the data located at the boundary of the subset, the data it needs to use will inevitably be located on other processors. Therefore, this problem needs to be solved by means of exchanging for the halo domain. That is, using finite difference discretization on a regular grid, the overlapping part between sub-regions is called the halo domain, and each process stores its boundary data in it. In a certain time step, these domains will transfer data with the surrounding processes, and then each process uses the obtained data to update the local halo domain to prepare for the calculation of the next time step. As shown in Figure 1, the processor P2 is surrounded by the HALO zone. In the semi-Lagrangian scheme, the width of the halo domain is determined by the maximum wind speed and its time step. When setting the global maximum wind speed in advance, the calculation on the processor P2 can obtain all possible structural information for the data required in the calculation process to form a fixed data transmission pattern.

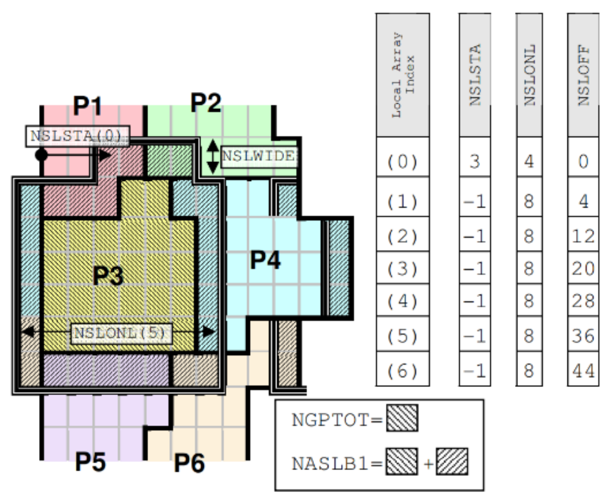

Fig. 1. The halo domain for the semi-Lagrange scheme in th

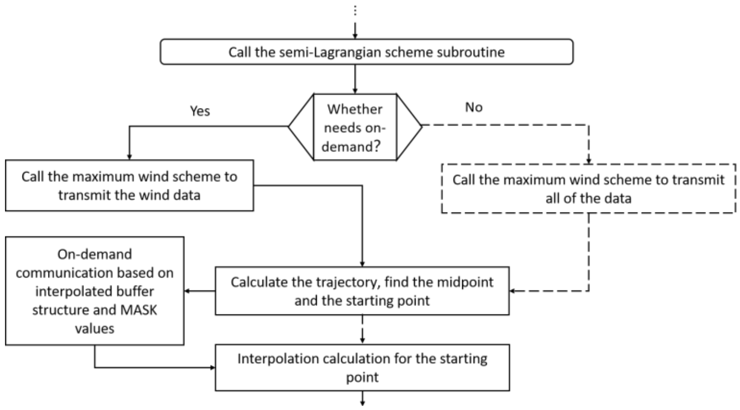

Fig. 2. The maximum wind scheme and the on-demand communication scheme flow charts in the YHGSM. The dotted line represents the maximum wind scheme and the solid line represents the on-demand communication scheme.

B. Status of the Parallel Semi-Lagrangian Scheme in the YHGSM

At present, two schemes, including a maximum wind scheme and an on-demand communication scheme, have been implemented in the YHGSM. These schemes are illustrated in Figure 2. In the maximum wind scheme, by setting the maximum wind speed in advance, it forms a fixed pattern to communicate, which is straightforward to implement. The disadvantage in this scheme is that many of the grid data values transmitted are not used in the interpolation computation, resulting in unnecessary communication overhead. In the on-demand scheme, the communication of the wind field is first performed according to the maximum wind scheme, and the trajectory corresponding to each grid point is calculated to find the starting point and the midpoint. After that, the other fields that are dependent on the trajectory are calculated, and the communication is performed according to the actual wind speed. When this scheme is used, during the semi-Lagrangian interpolation, the other field data (except the wind) no longer need to communicate all of the data in the halo domain calculated by the global maximum wind speed. Instead, only data for in the irregular areas calculated by local wind speeds are communicated. This can greatly reduce the communication volume, and the efficiency of the numerical forecast model is also significantly improved.

The on-demand communication scheme has achieved great success; however, the maximum wind scheme is still used for the wind data, which incurs some unnecessary communication overhead. The on-demand communication scheme is only used for the interpolation part, which can be done only if the trajectory is determined. If the maximum wind scheme with a global wind speed is used for the determination of the trajectory, the computational efficiency is inevitably limited. The global maximum wind speed is determined in advance and is statically configured in the setup phase. However, the actual maximum wind speed for each run changes, and often has a large difference from the global maximum value. If the difference between the actual wind speed and the maximum wind speed can be further reduced such that the model can run normally and not encounter an intersecting trajectory, then the unnecessary communication overhead can reduced. Therefore, investigating how to determine a reasonable maximum wind speed to meet the accuracy requirements of the forecasts and to reduce the unnecessary communication overhead as much as possible is an open and meaningful research problem.

III. A PARALLEL SEMI-LAGRANGIAN SCHEME BASED ON THE ADAPTIVE MAXIMUM WIND SPEED IN THE YHGSM

In the original model, since it is not known in advance whether the actual local maximum wind will exceed this threshold, so a higher threshold is set with a fixed value of 280 m/s as the model's abort value, and use it to determine the size of the halo domain for communication in the model to ensure the operation of communication. However, this threshold often exceeds the actual maximum wind speed encountered for each run; in some cases it can reach nearly twice the actual maximum wind speed. In order to minimize the unnecessary communication overhead caused by this setting, statistical analyses are presented in this section that re-evaluate the maximum wind speed encountered for each month to find a more reasonable value.

A. Monthly Distributions of Maximum Wind Speeds

The data that are used in this paper are the u and v components of the ERA-interim wind field from 2001 to 2018. is the data are divided into 60 layers in the vertical direction, and the top level is close to 80 km, which is the top of the YHGSM. The observation period includes 0, 6, 12, and 18 (hours). These cover the characteristics of the wind field in different time periods throughout the day, and has a certain representative significance. The final maximum values of the u and v components in each month are obtained from the daily values. It should be noted that the ideal maximum wind speed obtained here is slightly larger than the actual observed maximum value, that is, the final actual maximum wind speed is appropriately amplified. Here, we appropriately increase the setting of the maximum wind speed value to avoid setting the abort value in the model separately.

Figure 3 shows the monthly distributions of the ideal maximum wind speed and actual maximum wind speed over the years from 2001 to 2008. These range mainly from 120 to 250 m/s, and it is very few cases over 250m/s, which is much smaller than 280 m/s. Therefore, setting VMAX2 to 280 m/s to calculate the size of the halo domain in the model is an over-estimation.

If the value of VMAX2 is reduced, the unnecessary communication overhead can be controlled. In addition, the maximum wind speed varies periodically with time, exhibiting similar characteristics for the same month in different years. Therefore, the fixed global maximum wind speed can be modified to a maximum value changing with time, and then it can be introduced to the numerical forecast models to improve their computational efficiency. This approach, called the adaptive maximum wind scheme, is introduced in this paper. To accomplish this, it is necessary to introduce a variable for recording the date in the YHGSM, and a corresponding maximum wind speed should be selected as the initial value according to the initial date of the forecast. By using the monthly maximum value corresponding to the forecast date, adapted maximum wind speed can be much closer to the actual one. Based on this, the maximum wind speed distributed over the months from 2001 to 2018 are extracted. The values are presented in Table 1; one of these values is selected according to the forecast date to set VMAX2 in the model. In addition, the introduction of the adaptive maximum wind speed is only done for the initial value of the maximum wind speed, and does not impact any code or other settings of the model itself. In this way, the implementation is straightforward, and the unnecessary communication overhead is controlled. The anticipated result of reducing the communication overhead is an improvement in computational efficiency.

B. A New Parallel Semi-Lagrangian Scheme Based on the Monthly Adaptive Maximum Wind Speed

In the new scheme, the maximum wind speed used for each run changes according to the initial date of the forecast. Firstly, the initial date is obtained from the input data file, then the corresponding VMAX2 value is found accordingly for initialization, and finally the forecast is performed according to the selected maximum wind speed. In this way, the adaptive maximum wind speed is fixed during the model run, and the code structure of the model is unchanged. However, for different input data sets, the initial data acquired is different, so the maximum wind speed used is changed. This change occurs at the initial stage of utilizing the model and does not affect the overall code structure. Figure 4 shows the flow chart of the parallel semi-Lagrangian communication scheme based on the adaptive maximum wind speed in the YHGSM. In the upper part, the global maximum wind scheme is shown in A, and the adaptive maximum wind scheme is shown in B. The lower part is the same as that in Figure 1. Through the introduction of the adaptive maximum wind scheme, the difference between the maximum wind speed used and the actual speed is greatly reduced. This is beneficial to the reduction of the communication overhead, and the improvement of the computational efficiency.

IV. Numerical Experiments

The numerical experiments presented in this paper are performed on a parallel machine with 16-nodes connected by infiniband, where each node has two Intel(R) Xeon(R) CPU E5-2670 0 @ 2.60 GHz (cache 20480 KB) processors, and each processor has eight cores. The operating system is Redhat Linux version 2.6.32-220.el6.x86_64, the compiler used is Intel ifort

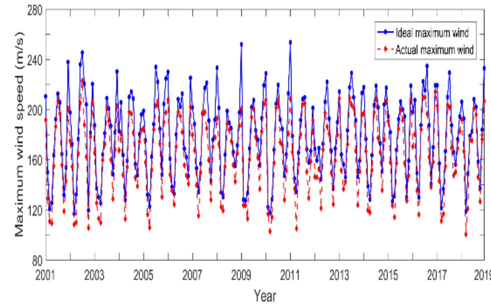

Fig. 3. Monthly distributions of the ideal and actual maximum wind speed over the years from 2001 to 2018. In the figure, the solid blue line is the distribution of the ideal maximum wind, and the red dotted line is the distribution of the actual maximum wind.

Version 11.1, and the inter-processor communication interface used is MPICH 3.2.0. The code is compiled with the -O3 option.

The effect of the adaptive maximum wind scheme introduced into the YHGSM is experimentally studied. For the maximum wind scheme and the on-demand communication scheme in the semi-Lagrangian communication phase, we count the total communication volume sent in bytes over all processors during the first five integration steps. In the experiments, the selected model resolution is T799L91. In this section, eight nodes with eight cores on each node are used to calculate the communication volume in part one, while sixteen nodes are used to give a comparison with eight nodes in part two when calculating the execution time. In addition, the unit of data volume in the experiments is in bytes.

A. Comparison of the Communication Volume

In the maximum wind scheme, the halo domain is estimated by the global maximum wind speed set in the initial phase. It does not change as the model executes. However, the problem is that in order to ensure the normal running of the model, the global maximum wind speed is measured as the maximum over past years for the entire world, covering all possible conditions (e.g., hurricanes, typhoons, and so on). This leads to an over-estimated value to approximate the actual maximum wind speed for a specific run, which introduces unnecessary communication overhead. By introducing the adaptive maximum wind scheme, the maximum wind speed is selected with a month-by-month consideration. The corresponding maximum wind speed is varied according to the initial date of the forecast, which is determined in the setup stage and does not change any of the code of the model. For the maximum wind scheme, the results with the global maximum wind speed and the monthly adaptive maximum wind speed are shown in Table 1.

It can be seen from Table 2 that the communication overhead is significantly reduced when the adaptive maximum wind speed is introduced, and the reduction ratio ranges from 10.57% to 41.16%. In addition, the reduction ratio is positively correlated with the maximum wind speed selected .

The on-demand communication scheme is based on an optimization with respect to the maximum wind scheme, which divides the parallel Semi-Lagrangian scheme into two parts, the trajectory determination and the interpolation on the starting point and the midpoint. For the trajectory determination, since the specific communication pattern is not known in advance, the wind field information are communicated with the maximum wind scheme. For the interpolation, the data need to be communicated are determined with the actual wind speed and an irregular halo domain. By this way, the communication pattern is optimized, and the communication volume is greatly reduced. However, in the first part, the maximum wind scheme is still used, and there is still lots of unnecessary communication volumes if a much larger value used for VMAX2. In addition, the improvement to the maximum wind setting still has minor improvements to the second part due to a smaller data structure. This improvement is not obvious compared to the first part, but it is still worth studying.

For the on-demand communication scheme, the experimental results for the global maximum wind speed and the monthly adaptive maximum wind speed are shown in Table 3. The reduction of the communication volume with the monthly adaptive speed is similar to that of the maximum wind scheme. They are significant, but the range of the reduction ratios is lower than those from the maximum wind scheme. They are distributed between 5.42% and 21.66%.

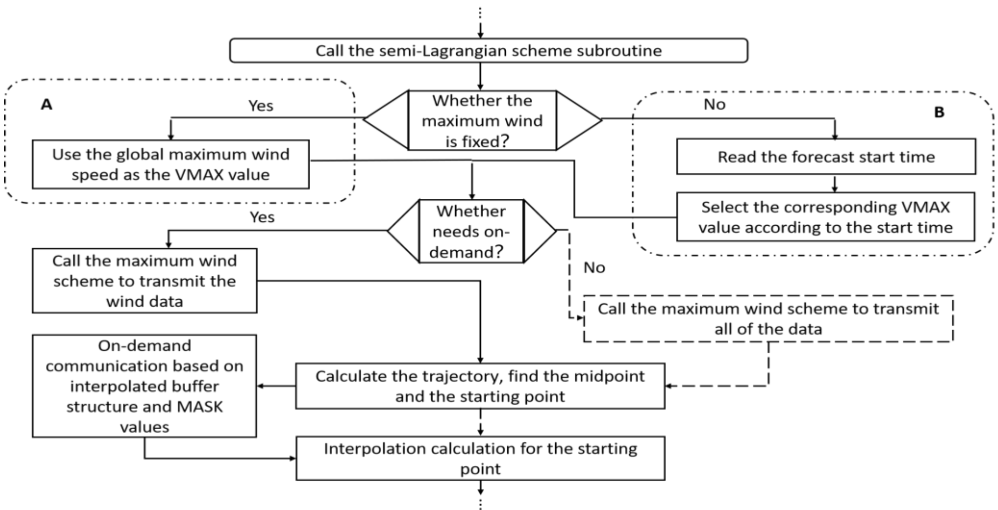

Fig. 4. The flow chart of the semi-Lagrangian communication scheme based on the adaptive maximum wind speed in the YHGSM

B. Comparison of the Parallel Execution Time of a Ten-Day Forecast

Since the data structure for the maximum wind scheme is simple and fixed, the unnecessary communication overhead is very large. At present, the on-demand communication scheme is mainly used in the YHGSM for the ten-day forecast. In experiments, a ten-day forecast over 1200 time steps with the on-demand communication scheme is executed, and the total overhead for the semi-Lagrangian computing as well as the total parallel execution time are measured for two cases: the global fixed VMAX2 and the adaptively selected VMAX2. In order to facilitate the research, a case study is selected in which the difference between the global maximum wind speed and the adaptive one is the most obvious (Reference to Table 1) , that is April 21, 2019. The results are shown in Table 4 and Table 5. It can be seen that for the new scheme, the total overhead for the semi-Lagrangian computing as well as the total parallel execution time for different steps are reduced in comparison to the original scheme. After 1200 time steps, they are reduced by 76.18 seconds and 226 seconds (approximately 6.25% and 1.44%) when using eight nodes, while they are reduced by 152.69 seconds and 184 seconds (approximately 13.87% and 2.10%) when using sixteen nodes. As the number of processors in the model increases, the proportion reduced of the total overhead for semi-Lagrangian computing increases, and the total parallel execution time also increases.

TABLE I. THE INITIAL VMAX2 SETTINGS IN THE GLOBAL MAXIMUM WIND SCHEME AND THE MONTHLY ADAPTIVE MAXIMUM WIND SCHEME WITH VALUES EXTRACTED FROM THE ERA-INTERIM WIND FIELD FROM 2001 TO 2018.

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
VMAX2 (Fixed)(m/s)	280	280	280	280	280	280	280	280	280	280	280	280
VMAX2 (Adaptive)(m/s)	253	208	170	149	188	236	246	235	205	163	205	238

TABLE II. COMPARISON RESULS FOR COMMUNICATION VOLUME: GLOBAL MAXIMUM WIND SPEED AND THE MONTHLY ADAPTIVE WIND SPEED FOR THE MAXIMUM WIND SCHEME.

Date	Global maximum wind (bytes)	Adaptive maximum wind (bytes)	Reduction (bytes)	Reduction ratio (%)
20180721	8585533160	7677997300	907535860	10.57
20180821	8585533160	6785109920	1800423250	20.97
20180921	8585533160	5908903050	2676630130	31.18
20181021	8585533160	5051766000	3533767190	41.16
20181121	8585533160	5908903050	2676630150	31.18
20181221	8585533160	6785109950	1800423260	20.97
20190121	8585533160	7677997300	907535920	10.57
20190221	8585533160	5908903050	2676630180	31.18
20190321	8585533160	5051766000	3533767240	41.16
20190421	8585533160	5051766000	3533767250	41.16
20190521	8585533160	5908903050	2676630210	31.18
20190621	8585533160	6785109950	1800423320	20.97

TABLE III. COMPARISON RESULTS FOR COMMUNICATION VOLUME: GLOBAL MAXIMUM WIND SPEED AND THE MONTHLY ADAPTIVE WIND SPEED FOR THE ON-DEMAND COMMUNICATION SCHEME.

Date	Global maximum wind (bytes)	Adaptive maximum wind (bytes)	Reduction (bytes)	Reduction ratio (%)
20180721	2815573266	2660824346	154748920	5.50
20180821	2767529660	2463153616	304376044	11.00
20180921	2727418282	2276193997	451224285	16.54
20181021	2755728676	2160839146	594889530	21.59
20181121	2800489508	2349265223	451224285	16.11
20181221	2868023796	2563683850	304339946	10.61
20190121	2855746054	2700997134	154748920	5.42
20190221	2794149050	2342924765	451224285	16.15
20190321	2748820688	2153931158	594889530	21.64
20190421	2746456428	2151605958	594850470	21.66
20190521	2788375082	2337140753	451234329	16.18
20190621	2837079794	2532708600	304371194	10.73

TABLE IV. COMPARISON RESULTS FOR TOTAL OVERHEAD FOR SEMI-LAGRANGIAN COMPUTING: GLOBAL MAXIMUM WIND SPEED AND THE MONTHLY ADAPTIVE WIND SPEED FOR THE ON-DEMAND COMMUNICATION SCHEME. THE INITIAL DATE OF THE FORECAST IS APRIL 21, 2019.

Step		**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1100**	**1200**
8Notes	Original scheme (s)	101.06	202.92	304.81	406.03	507.26	608.21	709.10	810.24	912.41	1014.06	1116.36	1218.75
	New scheme (s)	97.36	194.60	290.80	385.17	480.11	574.56	668.45	762.97	858.18	953.07	1047.70	1142.57
	Difference (s)	3.70	8.32	14.01	20.86	27.14	33.65	40.64	47.27	54.23	60.99	68.66	76.18
16 Notes	Original scheme (s)	94.38	189.17	283.26	376.99	471.11	565.41	656.79	748.54	837.89	926.54	1013.82	1100.48
	New scheme (s)	89.43	180.95	271.39	352.78	430.10	505.93	580.63	655.21	732.81	805.68	877.10	947.78
	Difference (s)	4.94	8.23	11.87	24.21	41.02	59.48	76.16	93.33	105.08	120.87	136.72	152.69

TABLE V. TABLE 5. COMPARISON RESULTS FOR THE TOTAL PARALLEL EXECUTION TIME: GLOBAL MAXIMUM WIND SPEED AND THE MONTHLY ADAPTIVE WIND SPEED FOR THE ON-DEMAND COMMUNICATION SCHEME. THE INITIAL DATE OF THE FORECAST IS APRIL 21, 2019.

Step		**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1100**	**1200**
8 Notes	Original scheme (s)	21:57	43:40	65:25	87:07	108:53	130:39	152:23	174:08	195:51	217:36	239:20	261:18
	New scheme (s)	21:29	42:58	64:29	85:52	107:20	128:49	150:18	171:44	193:09	214:37	236:04	257:32
	Difference (s)	0:28	0:42	0:56	1:15	1:33	1:50	2:05	2:24	2:42	2:59	3:16	3:46
16 Notes	Original scheme (s)	12:50	25：04	37：10	49：14	61：19	73：25	85：30	97：56	110：00	122：03	134：06	146：10
	New scheme (s)	12:26	24:31	36:22	48:11	60:01	71:52	83:42	95:47	107:38	119:28	131:17	143:06
	Difference (s)	0:24	0:33	0:48	1:03	1:18	1:33	1:48	2:09	2:22	2:35	2:49	3:04

V. CONCLUSION

The rapid development of high-performance computer technology has enabled and promoted the development of high-resolution numerical forecast models and algorithms. In the YHGSM, two schemes are currently available: the maximum wind communication scheme and the on-demand communication scheme. In the maximum wind scheme, a global maximum wind speed is set in advance, and the communication pattern is determined according to this value. Once the communication pattern is set, it does not change over time steps demand communication scheme, the maximum wind scheme is still adopted for the wind field. After the wind field is communicated, it is used to further determine the communication pattern of the other fields. This communication pattern communicates the necessary data, and the formed halo domain is often irregular, because it is adjusted according to the local wind field. As a result, the communication volume is greatly reduced. The implementation of the on-demand communication scheme is based on the wind field, however, the communication process of the wind field itself cannot use the on-demand communication scheme. It relies on the maximum wind scheme, which introduces a certain amount of unnecessary overhead communication.

In order to address this problem, we focus on the selection of the maximum wind speed in this paper. In fact, the maximum wind speed varies significantly with the time. However, in order to ensure the normal execution of the model, the value of the maximum wind speed, VMAX2, is often set too large, resulting in a substantial amount of unnecessary communication volume. In order to reduce the communication volume and the running time, we introduce an adaptive maximum wind scheme, in which VMAX2 varies according to the initial date of the forecast. In the initial stage of the model, the initial date is first read, and the maximum wind speed during the corresponding time period is extracted used in the model. In this way, the communication volume of the parallel Semi-Lagrangian scheme is further reduced, and the computation efficiency is also improved. Experiments show that when the maximum wind scheme is adopted, the communication volume with the adaptive maximum wind speed is significantly reduced, and the reduction ratio is between 10.57% and 41.16%. When the on-demand communication scheme is adopted, the reduction ratio ranges from 5.42% and 21.66%. This range is lower in comparison to results for the maximum wind scheme. In addition, for a 10-day forecast based on the on-demand communication scheme, when the global maximum wind speed is replaced by the adaptively selected one, the total overhead for semi-Lagrangian computing for the 1200 steps is reduced by 76.18 seconds (approximately 6.25%) in eight nodes and 152.69 seconds (approximately 13.87%) in sixteen nodes, while the total parallel execution time needed for all 1200 steps is reduced by 226 seconds (approximately 1.44%) in eight nodes and 184 seconds (approximately 2.10%) in sixteen nodes. As the number of processors in the model increases, the proportion reduced of the total overhead for semi-Lagrangian computing increases further, and the total parallel execution time increases further too.

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