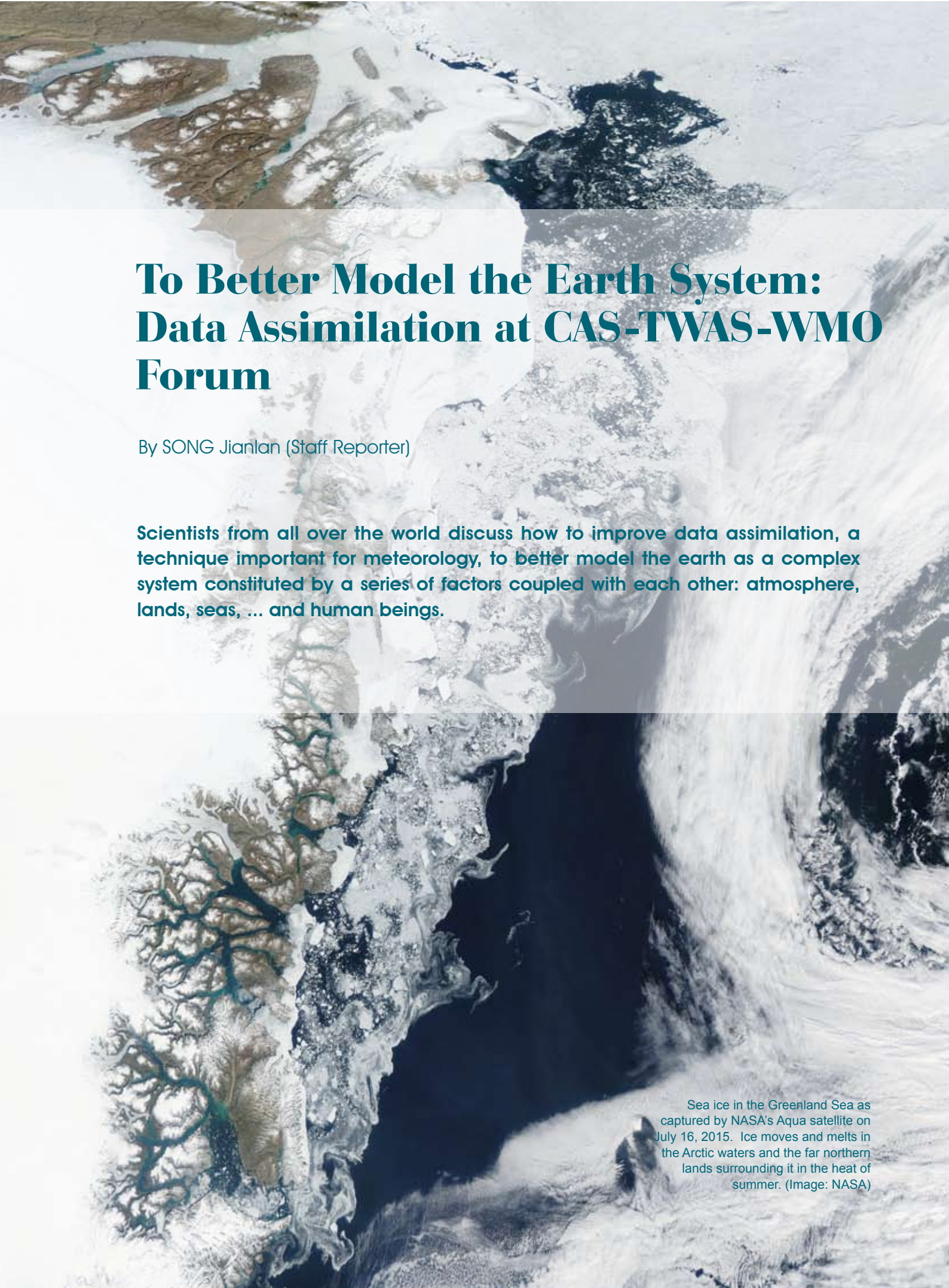
To Better Model the Earth System: Data Assimilation at CAS-TWAS-WMO Forum

By SONG Jianlan (Staff Reporter)

Scientists from all over the world discuss how to improve data assimilation, a technique important for meteorology, to better model the earth as a complex system constituted by a series of factors coupled with each other: atmosphere, lands, seas, ... and human beings.



Sea ice in the Greenland Sea as captured by NASA's Aqua satellite on July 16, 2015. Ice moves and melts in the Arctic waters and the far northern lands surrounding it in the heat of summer. (Image: NASA)

"One thing missing in today's research on climate change is the human system," commented Prof. Eugenia Kalnay from the University of Maryland, USA at the 14th CAS-TWAS-WMO Forum (CTWF).

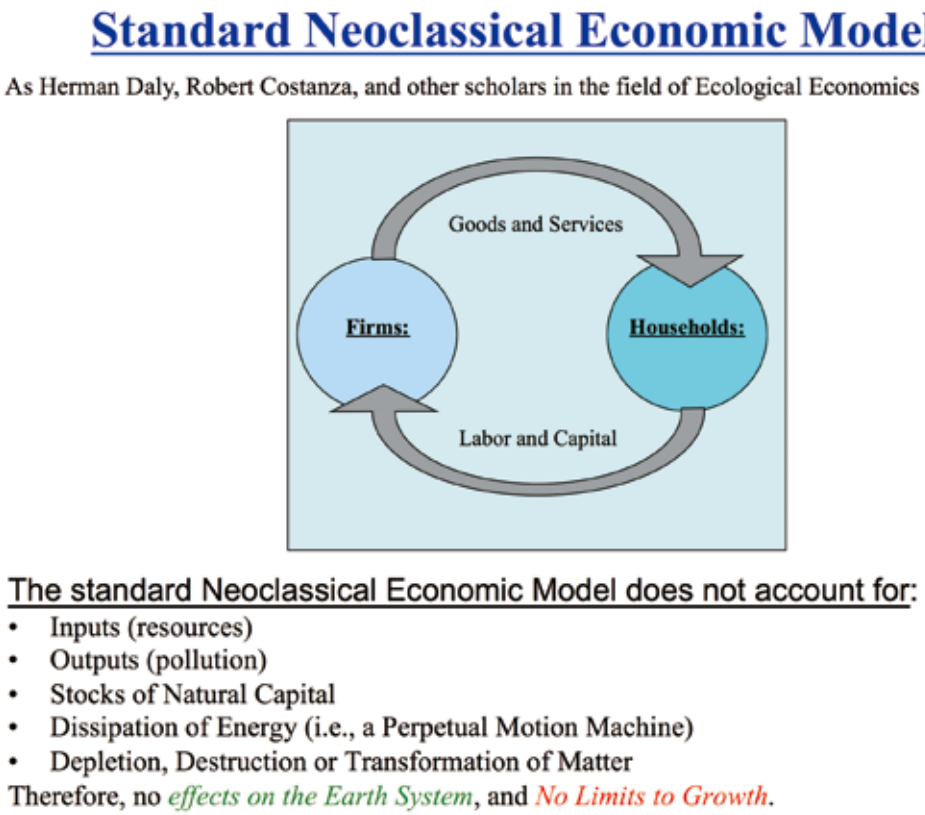
"Human beings have so big a population that we have dominated the earth system completely," Prof. Kalnay continued. "We keep interacting with nature, therefore when modelling the earth system, it is important to couple the human system to the earth system as real, as it is in reality, in the same way we do with ocean and land," she emphasized, suggesting that data assimilation has become so good, so sophisticated that it could open new doors to improving the models, and hence help fill this gap. "Without feedback from human population, the system cannot be accurate. I think data assimilation can help better couple the data to the earth system," she reiterated.

Prof. Kalnay is respected by scientists worldwide as the godmother of data assimilation, a technique important for meteorology, particularly weather forecasting. At the opening of the 14th CAS-TWAS-WMO Forum: Coupled Data Assimilation Symposium held from July 5 to 8, 2015, she gave a keynote speech titled "Population, Climate Change and Sustainability", sharing her concern about the effects of over consumption of natural resources by human population on the earth system. "Human population has grown by a factor of 10 or more since we started using fossil fuels... We are exploiting nature as if it was infinite. But it is not. Therefore we need to reduce the population as well as the consumption per capita," she remarked.

The CAS-TWAS-WMO Forum (CTWF) is a regular international forum initiated and founded in 2000 jointly by CAS, TWAS (the World Academy of Sciences, for the advancement of science in developing countries) and WMO (the World Meteorological Organization), as an effort to facilitate the study and solution of important scientific problems in climate modelling and prediction. To this end, the Forum holds a symposium annually with focus placed on a specific issue, to bring together high-level experienced mathematicians, physicists, atmospheric and oceanic

A view from the symposium. (Photo by courtesy of CTWF secretariat.)

In her keynote speech titled "Population, Climate Change and Sustainability", Prof. Eugenia Kalnay shared her concern about the effects of over consumption of natural resources by human population on the environment. (Photo by courtesy of CTWF secretariat.)



Myth of infinite growth: In her keynote speech, Prof. Kalnay couples human population with existing models to better estimate the future of the earth system. Instead of unlimited growth predicted by the "Standard Neoclassical Economic Model", human economy could collapse when a series of factors derived from human population are introduced, including depletion of natural resources and pollution sinks. "It is clear that growth cannot continue forever," she asserts. (Photo by courtesy of CTWF secretariat.)

scientists to exchange ideas, discuss scientific problems in depth and develop suitable solving methods.

Data assimilation was chosen as the central subject for this year's symposium. Efficiently integrating observations and modelling to achieve better estimation of future states, it is a crucial technique widely used in earth sciences, especially in forecasting of weathers, oceanic dynamics and *El Nino* phenomena. Prior to the symposium, a summer school was held from July 1 to 3 as a warming up to provide training for this technique.

Teller of Future and Past

Data assimilation refers to a mathematical physics way to combine (previous) forecast with observations to give the best possible estimation for the further forecast. "For example we have a forecast from yesterday about what will happen today, and also the data from the most recent observation," explained Prof. Kalnay: "This is like we first have the idea what will happen today, which is not accurate enough; and you combine that with the recent observations, which are also incomplete, subsequently you have the best estimation of the state of today, using the forecast as well as your observation.

"Basically it's combining in the best possible way the forecast with the observations to get the best estimation of atmospheric state, so that you can make another forecast, combining the observations we get the best estimation of the state of atmosphere," she continued to explain this subtle idea to the author.

It is like the models were "eating" the observations and assimilating them as an integral part of its output, said Prof. Kalnay. Further, the output forecast in return can be seen as the initial state for the next round of forecast.

"To accurately forecast the weathers of the following days, you need to input the data from today's observation, rather than those from last year: the more recent the data, the more accurate the forecast," advanced Prof. ZHU Jiang, head of Institute of Atmospheric Physics, CAS as well as the International Centre for Climate and Environment Sciences (ICCES), which is the organiser and host of the CTWF.

Jointly funded by CAS and TWAS, as part of the CAS-TWAS Centre of Excellence Project, ICCES is devoted to solving scientific problems in global climate and ecological environment changes, promoting further cooperation and communication with research institutes of both developed and developing countries. ICCES takes it as an important mission to provide developing countries with training programs and consulting services in the field of climate and environment sciences, and the launch of CTWF represents an effort for this sake.

Not all the observations can be used to improve weather forecasting, however, according to Prof. ZHU. "Currently only 5% data from satellite observations are used in forecasting," he introduced: "and the other 95% observations are left out from our models."

"Observations cannot be used by the model directly," he explained: "because very often the data are not what the model wants. For example, the data from satellite observations are images, whereas what the model needs are changes in wind, temperature, humidity and pressure parameters, rather than images. Therefore before inputting into the model, you need to translate the black/white photos into such parameters. In the process of translation you need to couple the characters of the images with the parameters of wind, temperature, humidity and pressure from land-based observations, ideally via an optimal coupling. That is why we need data assimilation and coupled data assimilation."

"In practice all the observations have to go through data assimilation before being input into the model," he added.

Prof. Kalnay and Prof. Takemasa Miyoshi from the RIKEN Advanced Institute for Computational Science, Japan at the poster session of the 14th CTWF. (Photo by courtesy of CTWF secretariat.)

It takes long-term, intensive efforts by many people to develop a system of data assimilation, however. According to ZHU, such assimilation must agree with the characteristics of the data errors, and meanwhile the features of the model itself also need to be considered. Therefore it is not easy to establish a model-specific method for data assimilation.

Aside from weather forecasting and climate prediction, data assimilation can also help us understand the past climate. Meteorological observations can be traced back to the 1950s. "But at that time they occurred sporadically, producing data of low resolution. Using state-of-the-art techniques from today, we can assimilate the data from the 1950s, to better understand the situation of that decade," Prof. ZHU introduced.

This makes data assimilation an important tool for climate change research and prediction.

"Such practice, using the latest techniques to analyse the data from the past, is called the re-analysis of data. Prof. Kalnay was the first expert to do this," Prof. ZHU added.

Rewarding Training and Discussion

The first part of the 14th CTWF, the summer school provided intensive training in fundamentals of data assimilation, and the second part, the symposium specifically focused on coupled data assimilation, offering a platform for the participants to share the latest progress of their work in this area.

For the summer school, the host invited the most successful researchers in this field from all over the world to teach courses. Contents covered different methods involved in data processing and assimilation on different frontiers, including variational data assimilation, ensemble Kalman filter, nonlinear and particle filters, and hybrid and coupling of ensemble and variational data assimilation. Beginning with fundamental mathematic methods, the contents gradually evolved to applications in different areas, like oceanic, atmospheric, and ecological and pollutant modelling.

The subsequent symposium involved 12 sessions, each focusing on a specific area, covering a spectrum ranging from coupled ocean-atmosphere data assimilation, coupled biogeochemistry-land surface-atmosphere data assimilation, coupled atmosphere-chemistry data assimilation, coupling and hybrid data assimilation methodology, regional scale data assimilation, computational algorithms and big data, to non-linear data assimilation approaches and particle filtering.

The lectures of each session were arranged in a sandwich sequence, leading by one or two invited lectures

Snapshot of a plenary discussion. (Photo by courtesy of CTWF secretariat.)

lasting for 35 minutes given by outstanding scientists, introducing their own work in different issues. These leading lectures were followed by some shorter invited speeches, and then some presentations given by participants of the summer school, sharing their progress, mostly case studies. A plenary discussion session was available after every three or four lectures.

Prof. Kalnay gave two one-hour courses under the titles "Observation Impacts and Targeting" and "Assimilation of Rainfall Observation" respectively at the summer school, and later an invited lecture titled "New Applications of Data Assimilation to Climate Systems: Correcting the Model Biases Based on Analysis Increments, Effective Assimilation of Precipitation, Proactive QC, and Strongly Coupled Data Assimilation" at the subsequent symposium, aside from her keynote speech.

Other distinguished speakers included Prof. ZHANG Shaoqing from Geophysical Fluid Dynamics Laboratory, USA, Prof. Christian Keppene from National Aeronautics and Space Administration (NASA), USA, Prof. WU Xingren from Environmental Modelling Center, National Centers for Environmental Prediction under the National Oceanic and Atmospheric Administration, USA, Prof. Francois Counillon from Nasen Environmental and Remote Sensing Center, Norway, Prof. Richard Menard from Canadian Meteorological Center, Canada, Prof. ZHANG Fuqing from Pennsylvania State University, USA and Prof. Peter Van Leuwen from University of Reading, UK, among others.

According to participants, the Forum was very rewarding.

"I got so many new concepts, so many new ideas on how to relate my image processing to data assimilation," said Prof. Mussarat Abdullah from the COMSATS Institute of Information Technology, Wah Cantt, Pakistan. "The three-day summer school was very informative about what actually is going on with data assimilation, and it gave us enough information on the fundamentals to understand the later contents presented at the symposium. My actual field of specialization is image processing with computers, but data assimilation can be used in my work very efficiently. I think I can get very good experience in my own field using this technique and I expect that something very interesting can come out," she said with a joyful smile.

She also welcomed the sandwich-like arrangement of the agenda. "You never get bored," she affirmed.

"I appreciate the great smoothness in the connection of speeches in the whole summer school as well as the symposium," she added: "Everything was so well organized, every speaker was so well prepared, definitely including me," she laughed.

Prof. Mussarat Abdullah gave a presentation at the symposium titled "Data Assimilation as Prediction for Weather Forecast Using Image Processing".

Even Prof. Kalnay found the lectures interesting. She attended all the lectures, saying she learnt a lot from the speakers.

Community Assimilation

Particularly, Prof. Mussarat Abdullah appreciated the considerate preparation of meals especially for Muslims.

Prof. Mussarat Abdullah from the COMSATS Institute of Information Technology, Wah Cantt, Pakistan gives a presentation at the symposium, applying the technique of data assimilation she learnt at the summer school to her image processing. (Photo by SONG J.)

Participants of the Forum come from both developed and developing countries. (Photo by courtesy of CTWF secretariat.)

Prof. Richard Menard from Canadian Meteorological Center, Canada gives an invited speech titled "Coupled Chemistry-Dynamics Data Assimilation in the Stratosphere" at the symposium. (Photo by courtesy of CTWF secretariat.)

"You know we are fasting, therefore I can't eat anything during the daytime," she said: "So happy that they arranged the dinner with many dishes that you could really enjoy, knowing you did not have anything for the whole day. It is a very good thing for us. When we came to dinner the first day of the symposium, we got a Muslim table specially organized for us. We enjoyed the Forum to the same extent as non-Muslims. We really did not feel any difference or segregation. We are very happy for that."

"It is the first time for me to attend such a wonderful, very appreciable data assimilation workshop, and I learnt a lot," remarked Dr. Jing-Jia Luo from the Australian Bureau of Meteorology at the closing ceremony. "I did something before with a very simple coupled data assimilation, and thought that the fully coupled data assimilation model would be just too technical and too complicated. But now standardized packages for data assimilation have been developed, and helped broaden the world of data assimilation community so quickly. It's so convenient now you are standing with a panel of experts around, with whom you can talk anytime. So I think it is very good to be involved in the group. I think I have been assimilated into the group. Of course I will ask the experts more questions when I am back home, and I hope you guys can assimilate more and more scientists from different areas into the community," he anticipated.