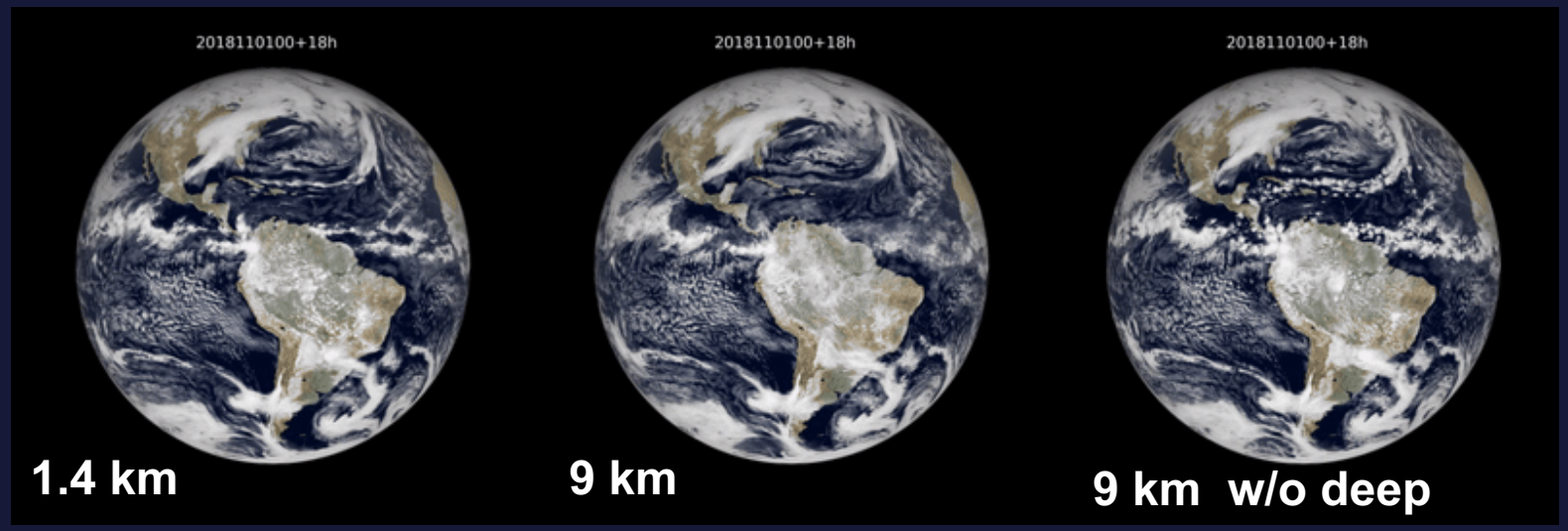
Towards a Digital Twin

Nils P. Wedi
European Centre for Medium-Range Weather Forecasts (ECMWF)



Snapshots of 4 months simulated top-of-the-atmosphere radiation fluxes

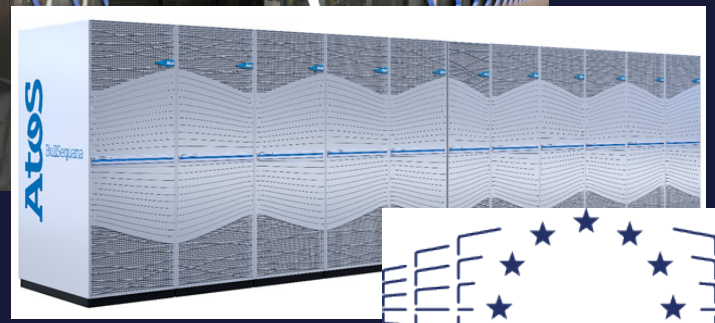
How the EC's DestinE programme transforms environmental policy making – Digital twins as a step-change for Earth-system modelling and data assimilation

ECMWF

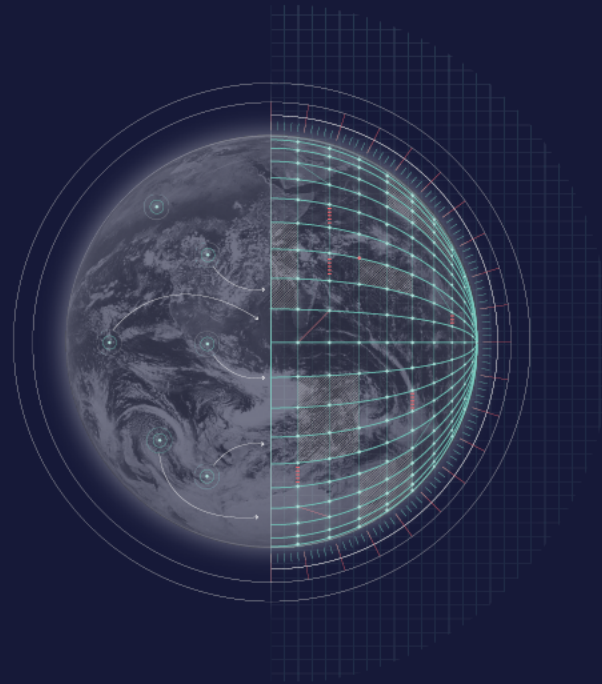
Track Record of efficient HPC use on some of the largest supercomputers in the world

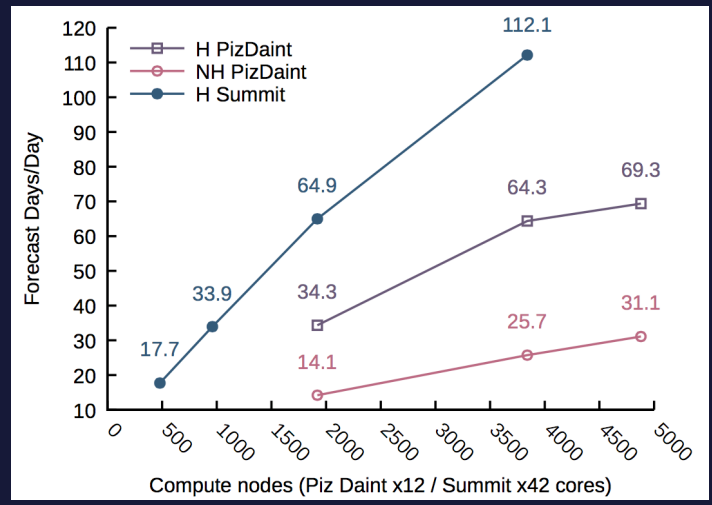
PizDaint

Summit



ECMWF's next gen

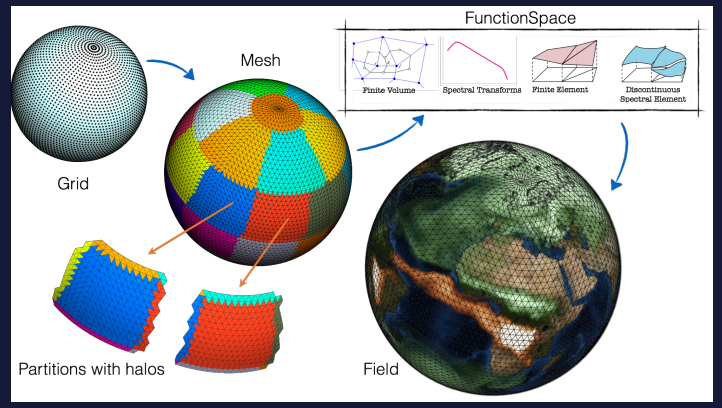




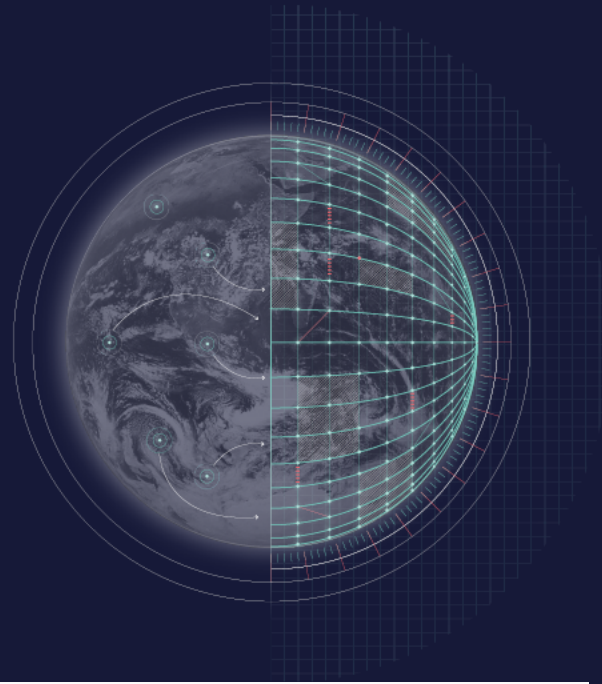
Wedi et al, 2020

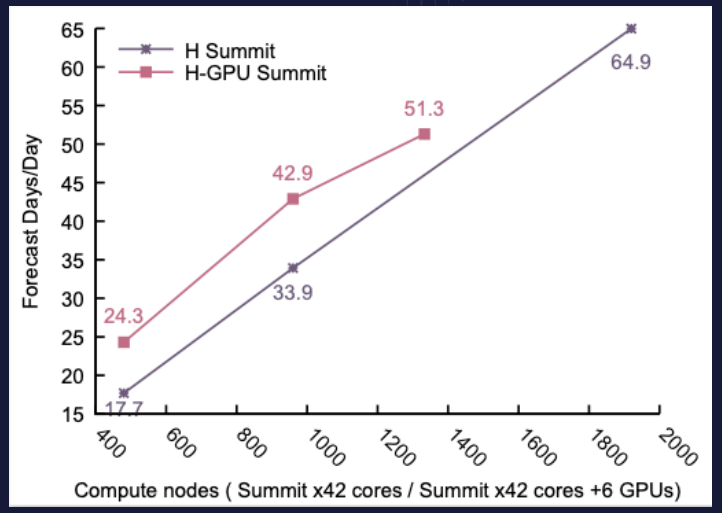
2020 HPCwire Awards
Readers' Best Use of HPC in Physical Sciences – ECMWF & ORNL

Build on a solid technological background



Atlas: a library for NWP and climate modelling
Deconinck et al. 2017
Mueller et al, 2019





Heterogeneous CPU-GPU compute

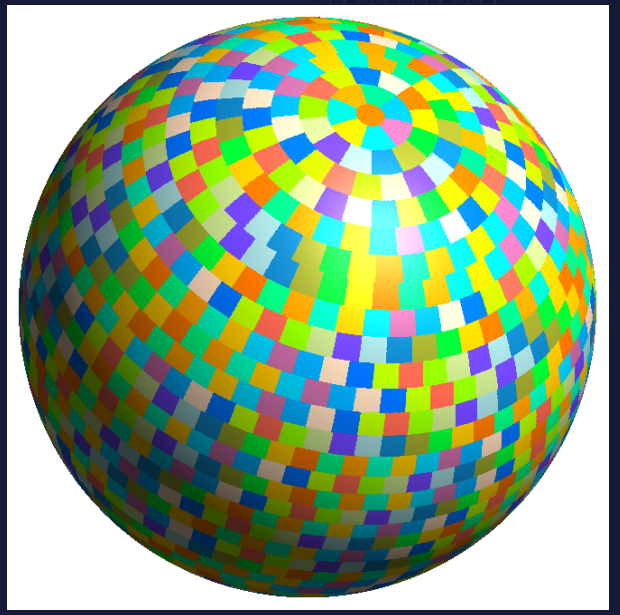
Innovative I/O management, data compression and governance

ECMWF NWP

6,599,680 points x 137 levels x 10 variables
at ~9km ~ **9 Billion points** **or** **~100TB/day**

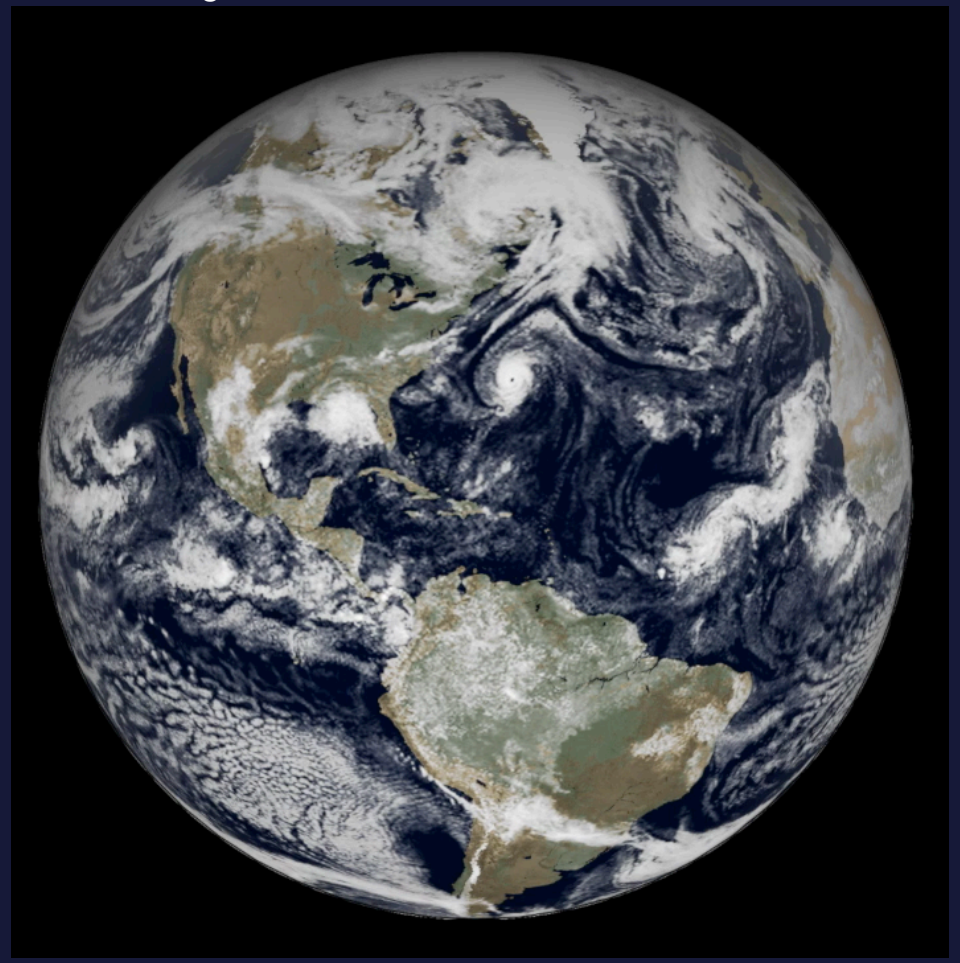
Digital Twins (DTs)

TCo7999 L137
256,800,000 points x 137 levels x 10 variables
at ~1,4km
352 billion points **x 960 pp steps ==**
~100TB/simulated month
Summit simulation

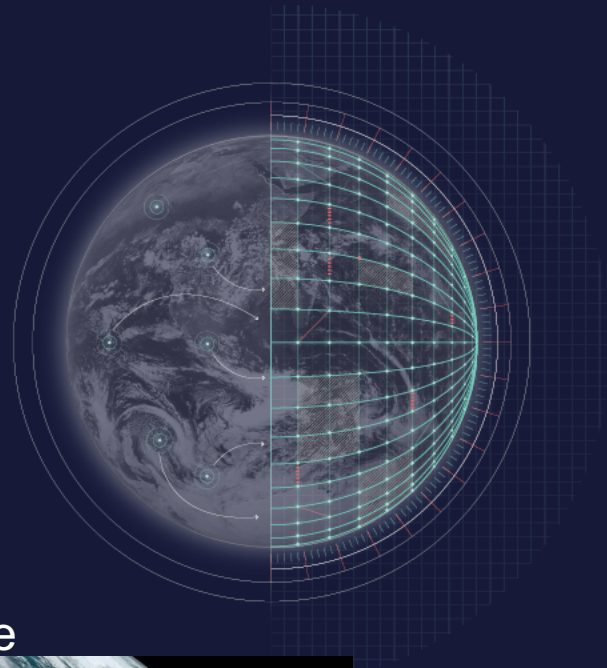


ECMWF pioneered Ensemble Forecasting

Simon Lang & Irina Sandu



9km TCo1279L137 *51 Ensemble members* 20200913 00 UTC + 41 h



5 tropical cyclones on one picture

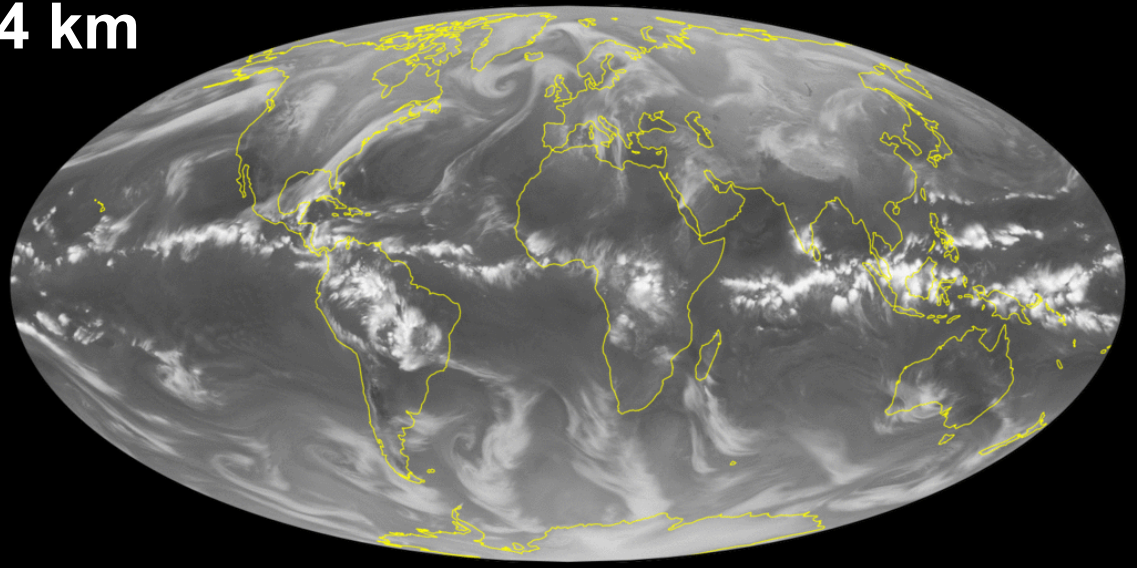
NOAA

Comparison of simulation output in observation space

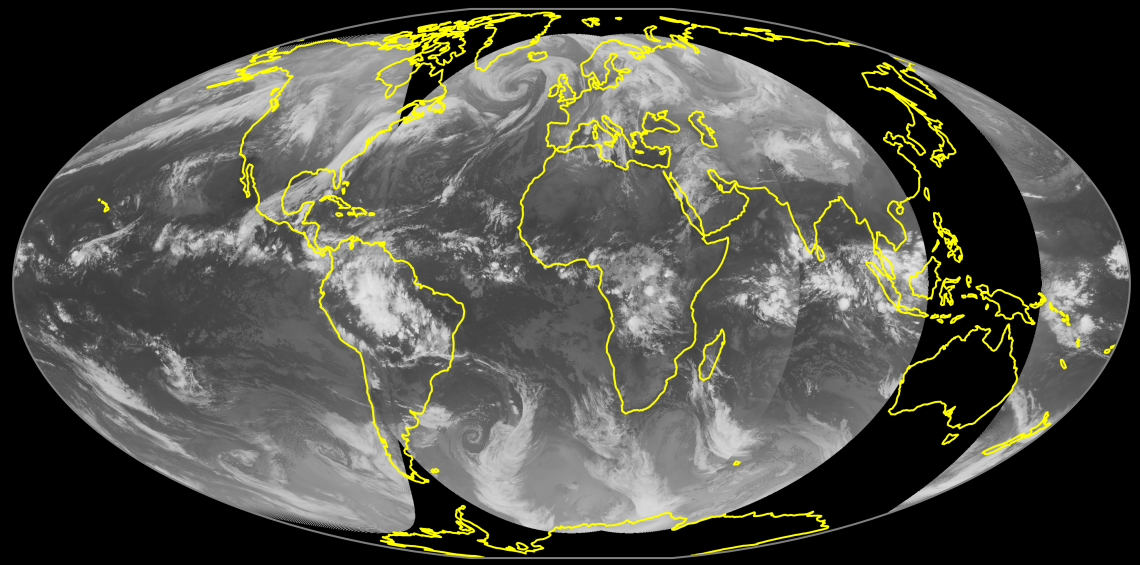
Combining multi-instrument and multi-channel satellite information with model data is an important aspect of ECMWF's data assimilation

2018110100+48h

1.4 km



Meteosat-8, Meteosat-11 and GOES-15
2018110300



Deep convection explicitly resolved globally

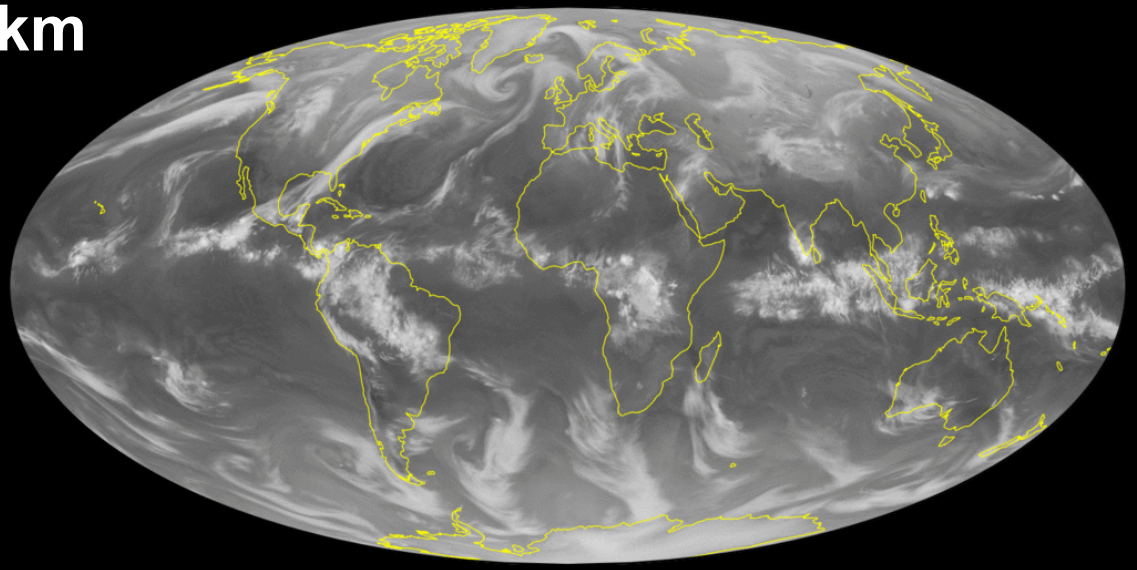
Philippe Lopez & Cristina Lupu

Comparison of simulation output in observation space

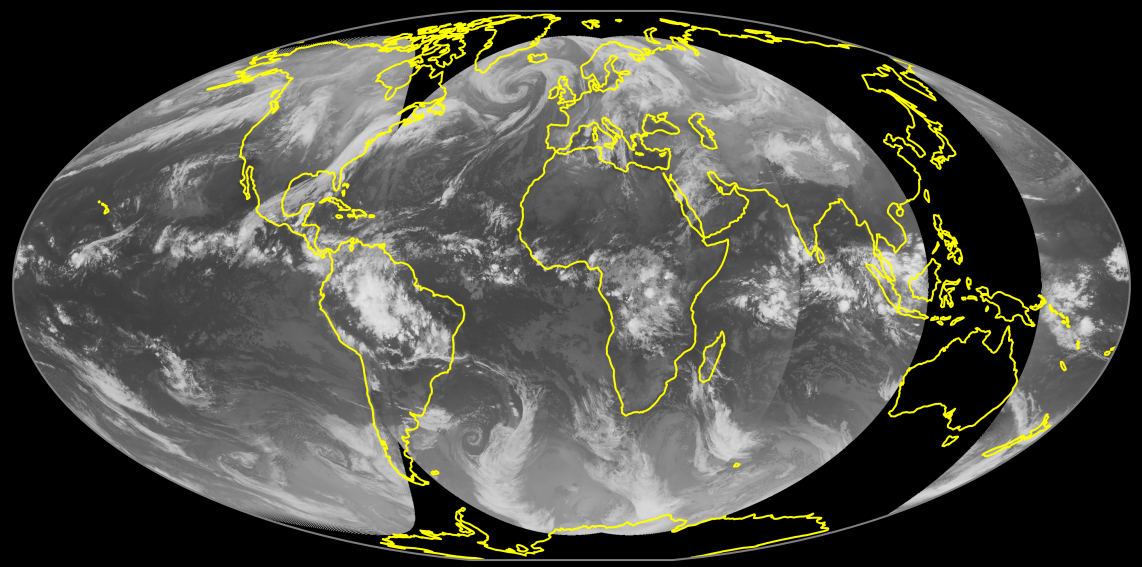
Combining multi-instrument and multi-channel satellite information with model data is an important aspect of ECMWF's data assimilation

2018110100+48h

9 km



Meteosat-8, Meteosat-11 and GOES-15
2018110300

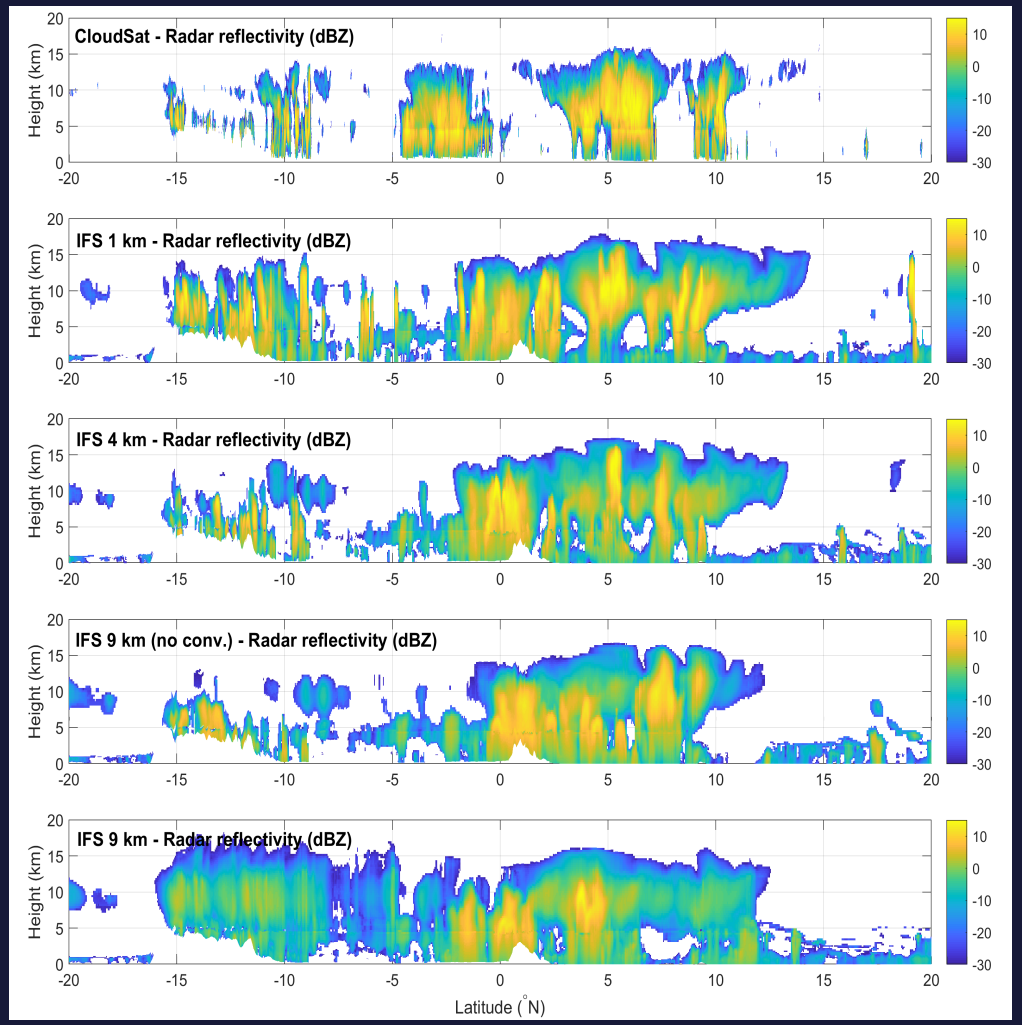


Deep convection parametrised

Philippe Lopez & Cristina Lupu

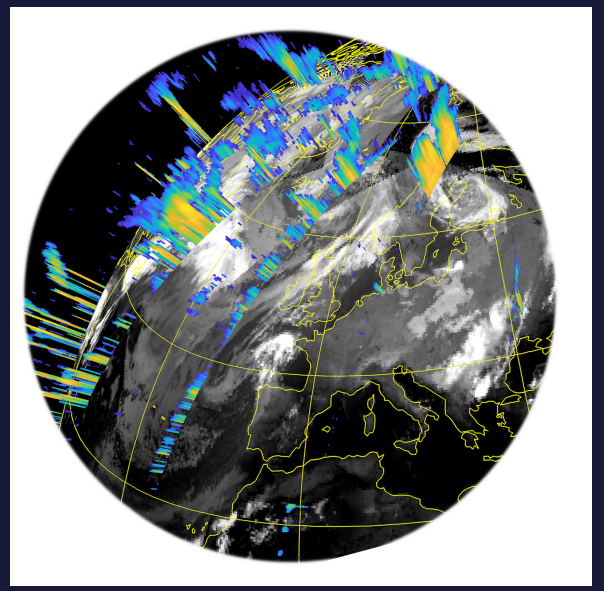
Data assimilation

EarthCARE mission preparations

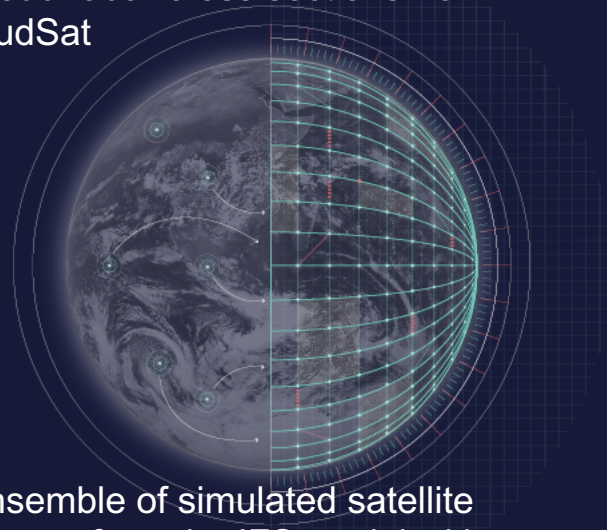


Direct comparison in observation space

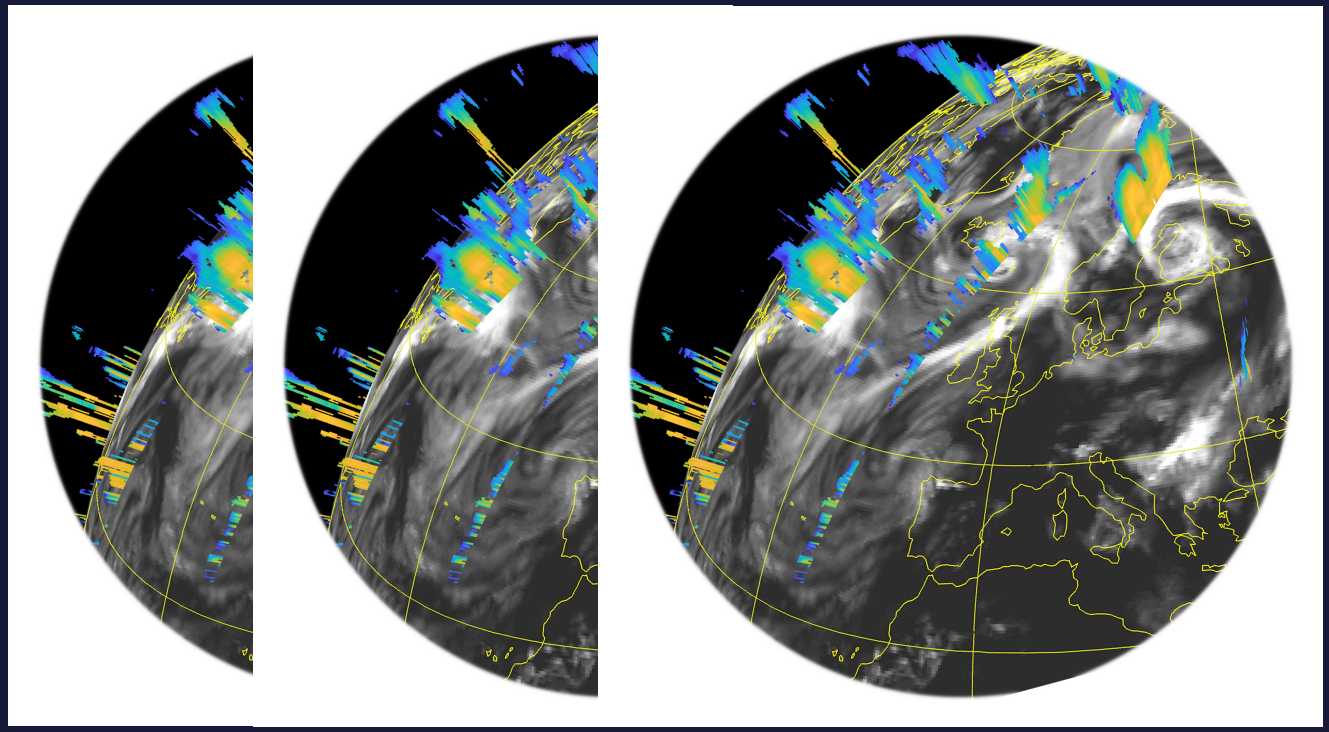
Mark Fielding and Marta Janiskova

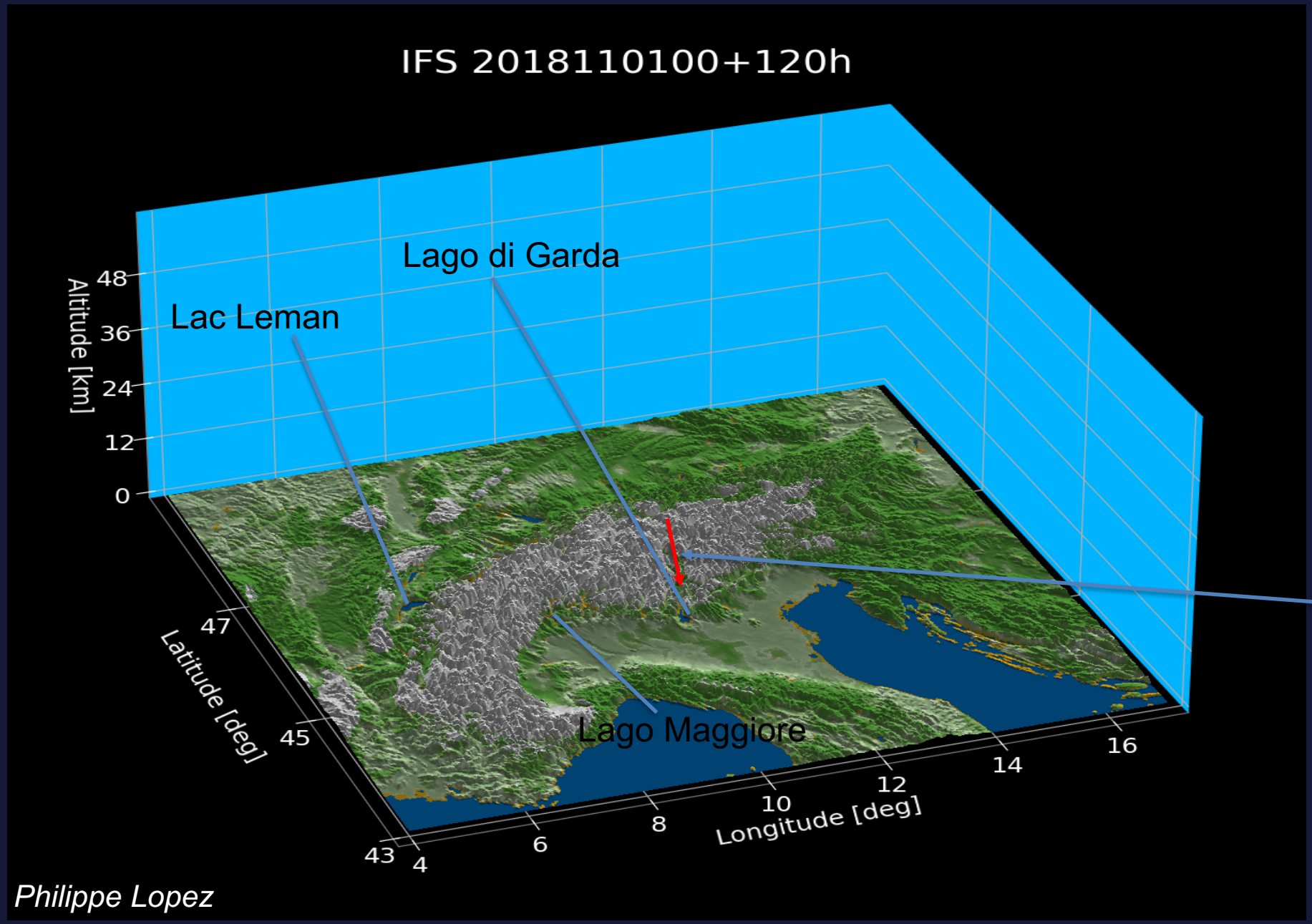


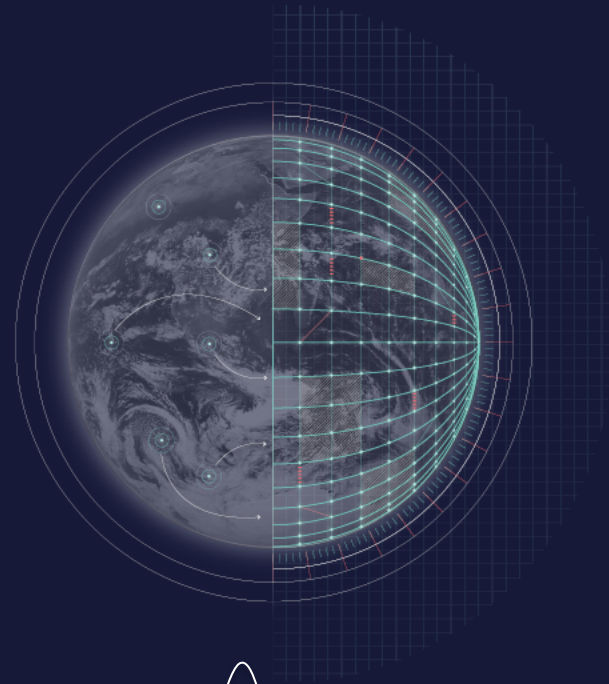
MODIS aqua infrared channel
+ cloud radar cross sections from CloudSat

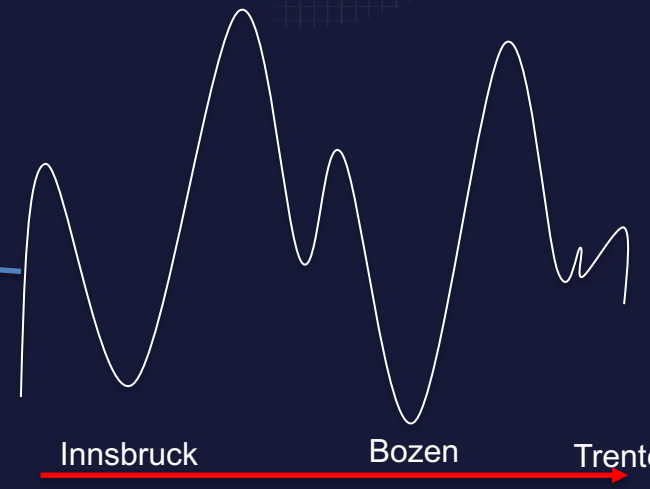


Ensemble of simulated satellite images from the IFS model with analysed cross-section cloud profiles

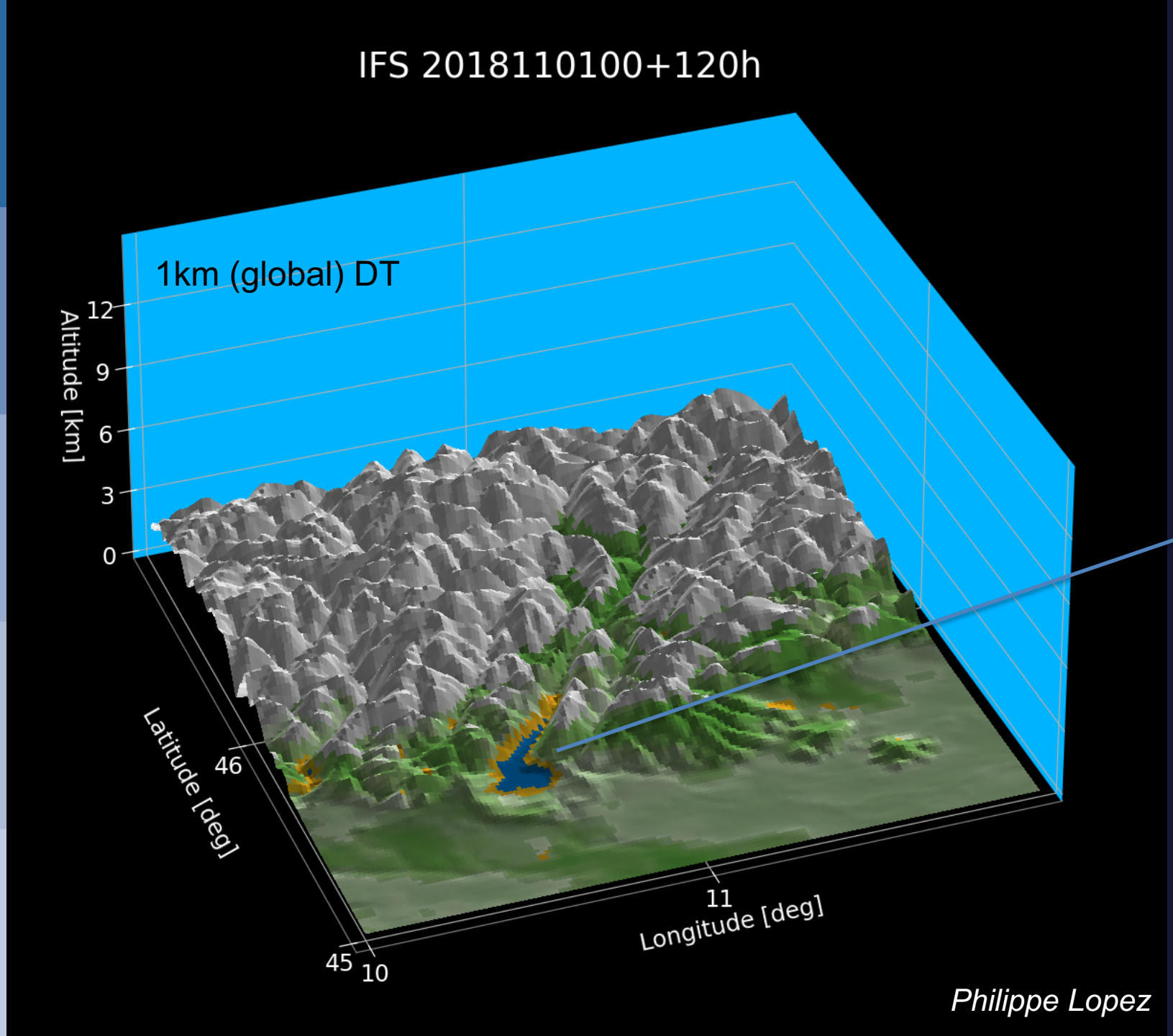


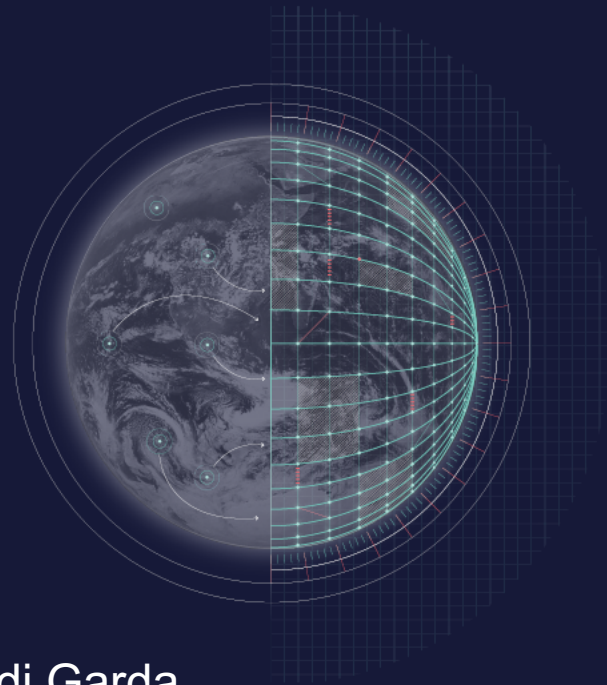






Different climate zones and atmospheric transport barriers

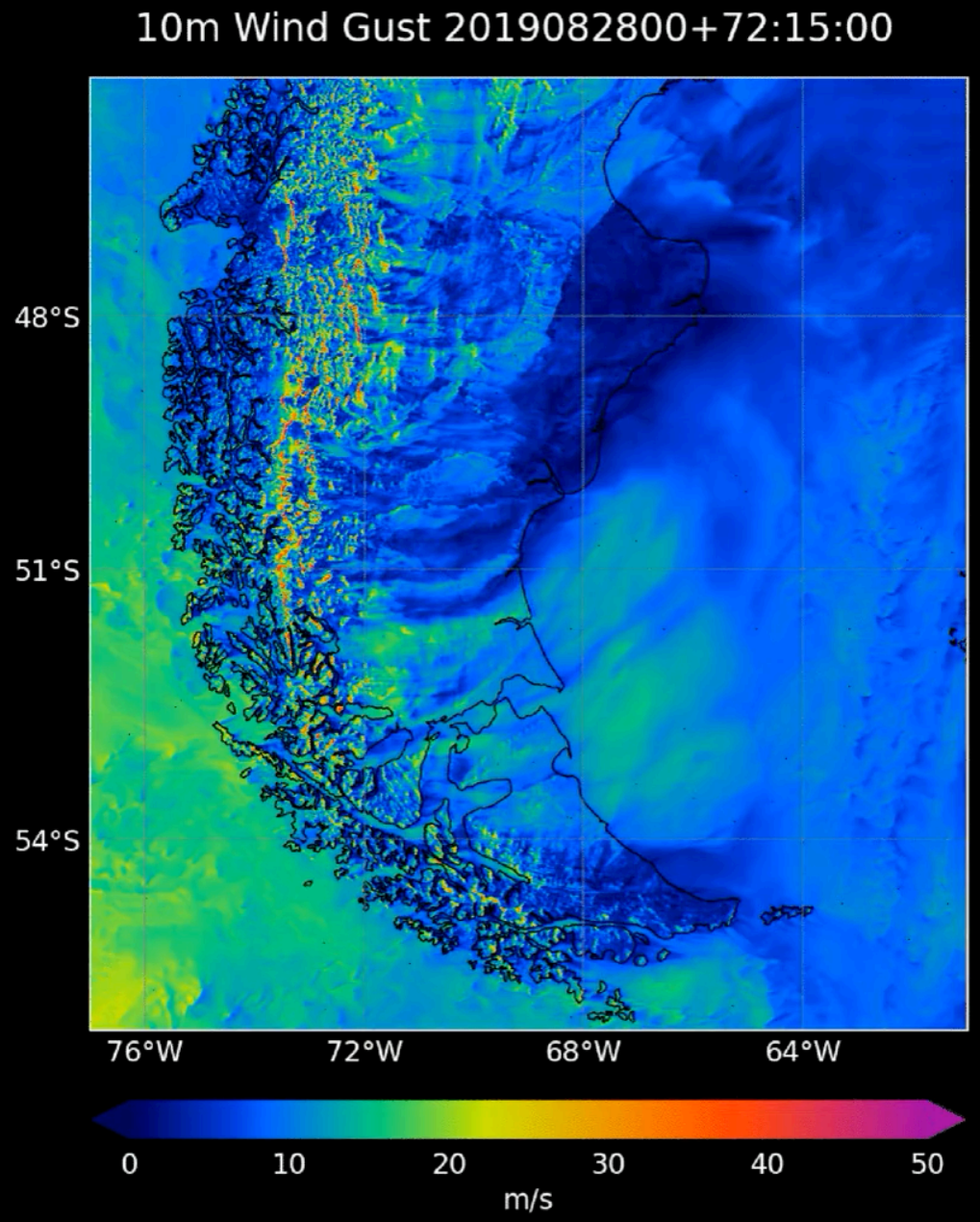


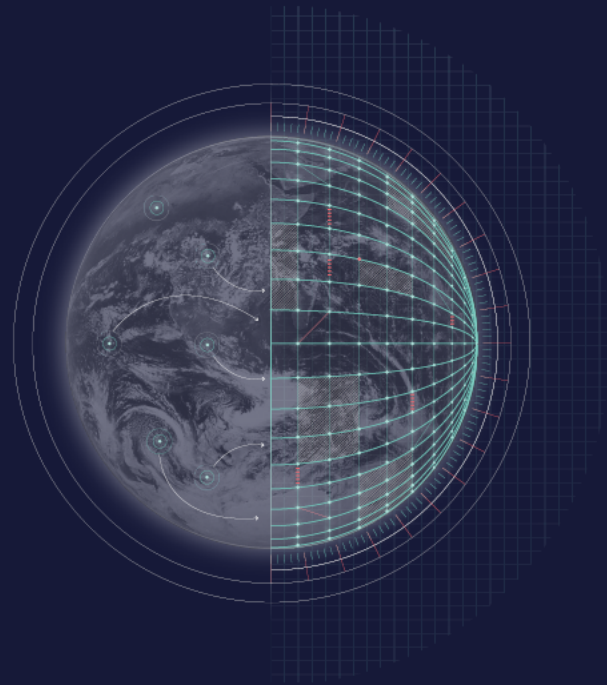


Lago di Garda

1

Patagonia Wind-gusts

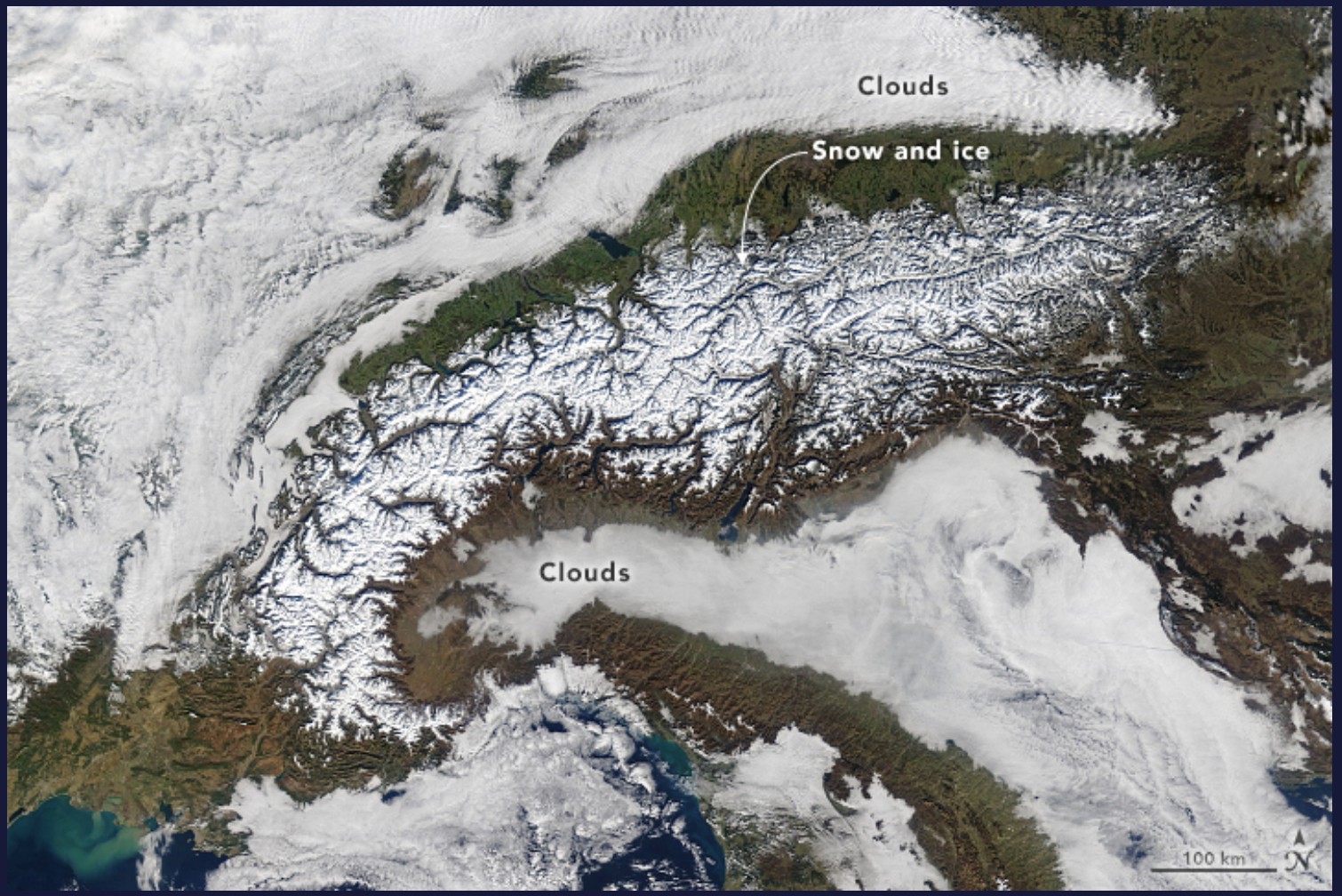




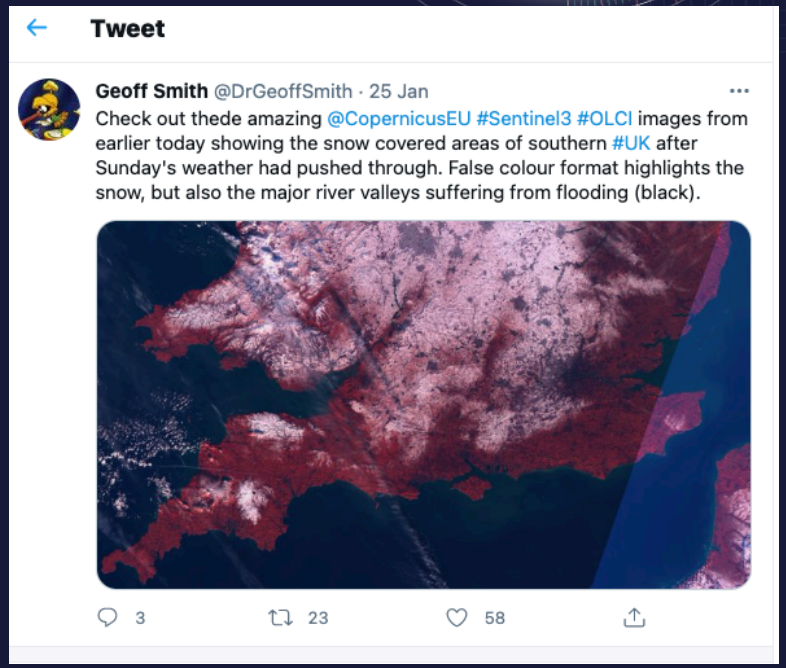
Multiscale
severe wind events
across complex topography

Philippe Lopez

Combining AI and data assimilation tools with physical and dynamical constraints



NASA Feb 2018, https://earthobservatory.nasa.gov/images/91658/snow-and-clouds-around-the-alps



UK snow and flooding areas

ESA SENTINEL-3 Ocean and Land Colour Imager (OLCI)

Increased realism in water cycle reservoir representation at 1km

Gianpaolo Balsamo, Ioan Hadade, Gabriele Arduini, Souhail Boussetta, Joey McNorton, Margarita Choulga, et al.

Offline Surface Modelling with **increased performance** land - surface model at **1km at ECMWF**

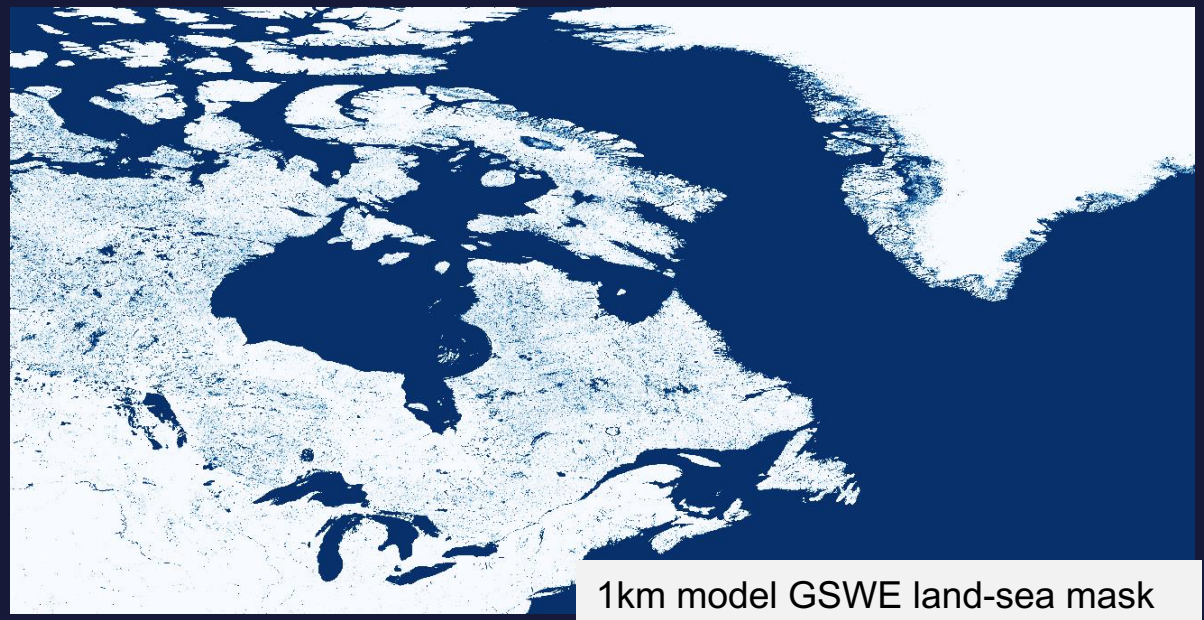
Increased realism of

- Land use and land cover (use of ESA-CCI)
- Coastal areas and lakes (use of GSWE)
- Snow over orography & catchment hydrology
- Urban areas

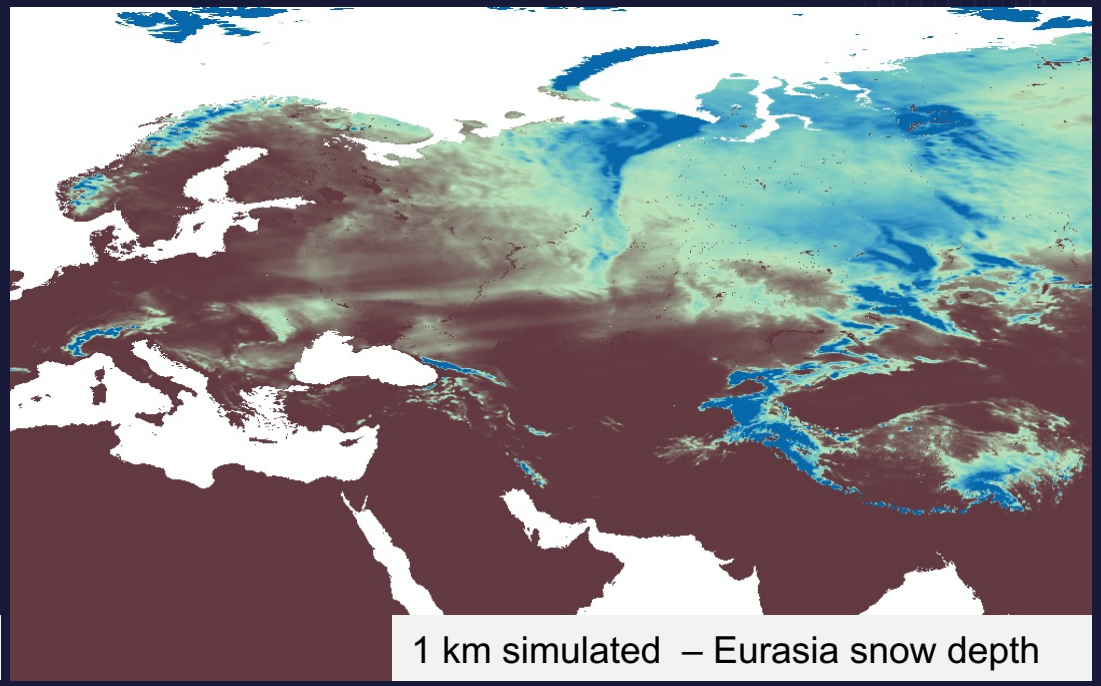
Prerequisite for improved analysis of

- skin temperature
- anthropogenic emissions

Resolution	Configuration	Performance SYPD
9km (**HRES** & ERA5Land)	TCo1279	**~ 8**
1km	TCo7999	**~ 1**



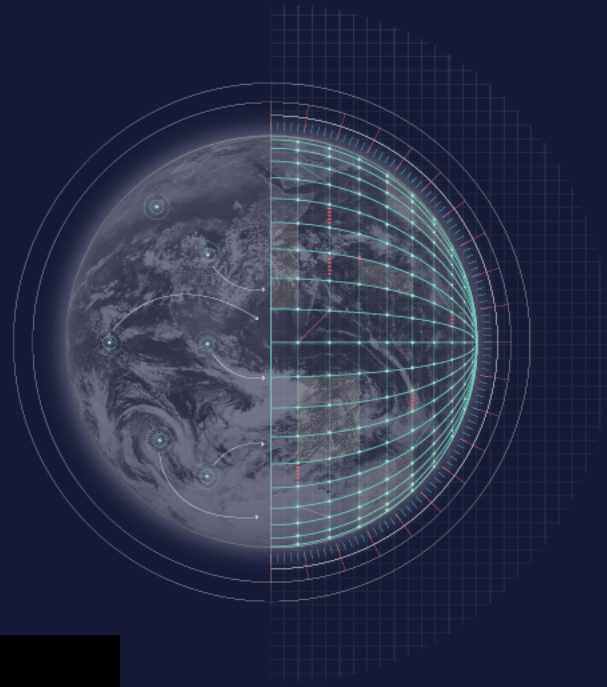
1km model GSWE land-sea mask



1 km simulated – Eurasia snow depth

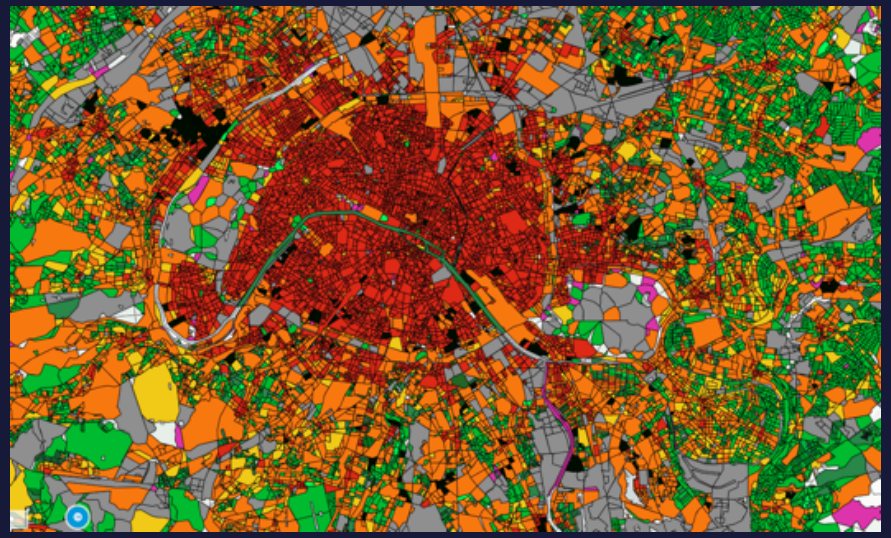
ECMWF

Bridging gaps to metre-scale regional refinement

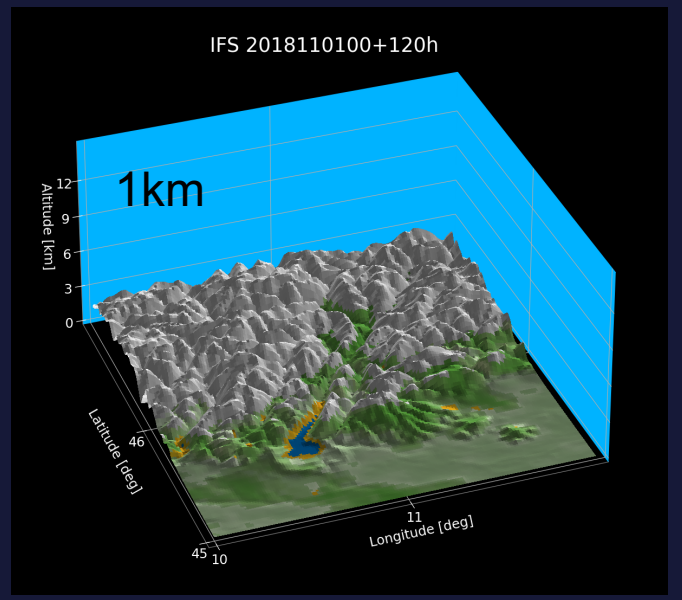


- metre-scale observations,e.g. IoT, social movement and urban planning data, etc.
- **WMO Research Demonstration Project "Paris Olympic Games 2024"**

http://www.umr-cnrm.fr/RDP_Paris2024/



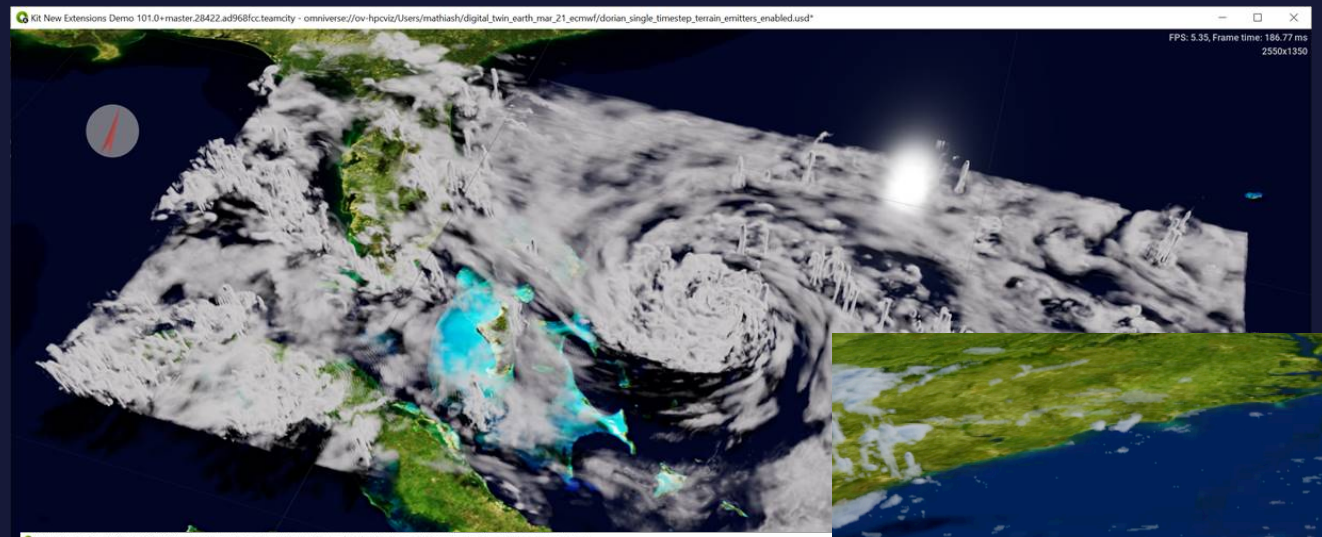
Buildings typology:
Paris and inner suburbs.
Source: mapuce.orbisgis.org

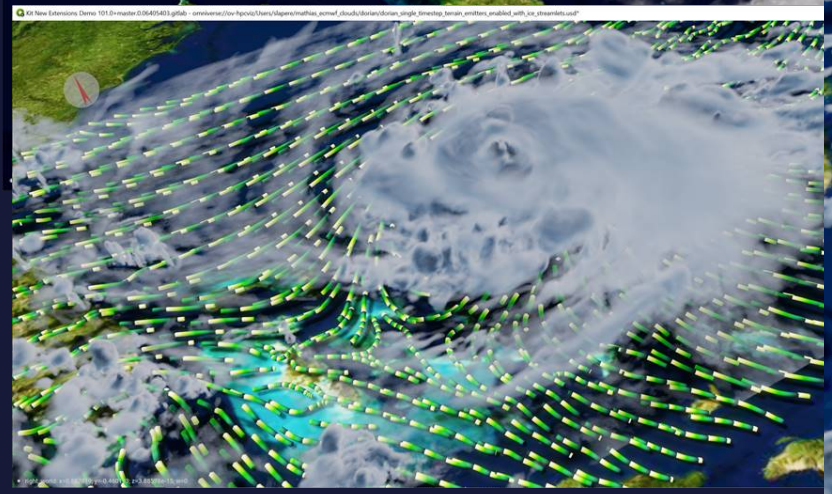


OMNIVERSE

Mathias Hummel, Peter Messmer (NVIDIA); Pedro Maciel (ECMWF)

4-day global forecast at 1km of Hurricane Dorian in August 2019 on Summit



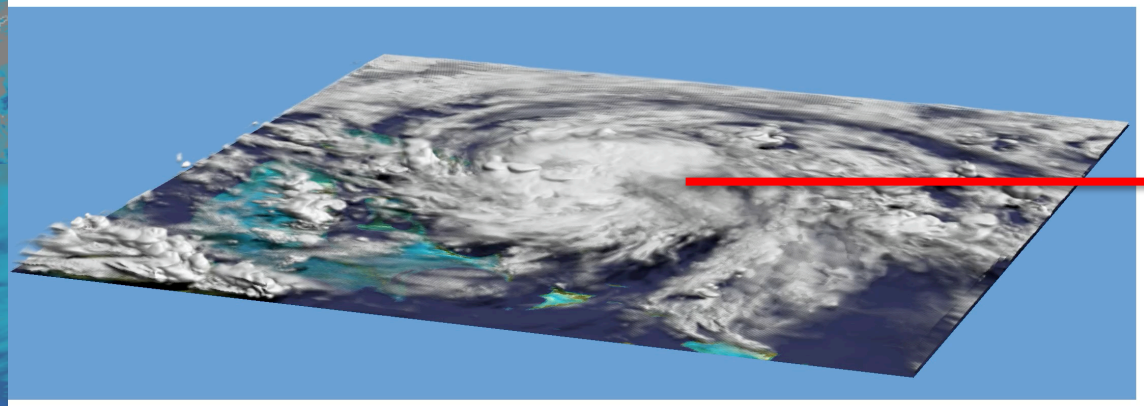


First glimpse of GPU accelerated interaction with 1km global forecast data …

Sylvie Lamy-Thepaut

4-day 1km forecast of Total column liquid water

Hurricane Dorian



Robin Hogan

Prepare for silent killers …
e.g. impact of powerful storms on sea-ice enhancing Arctic amplification

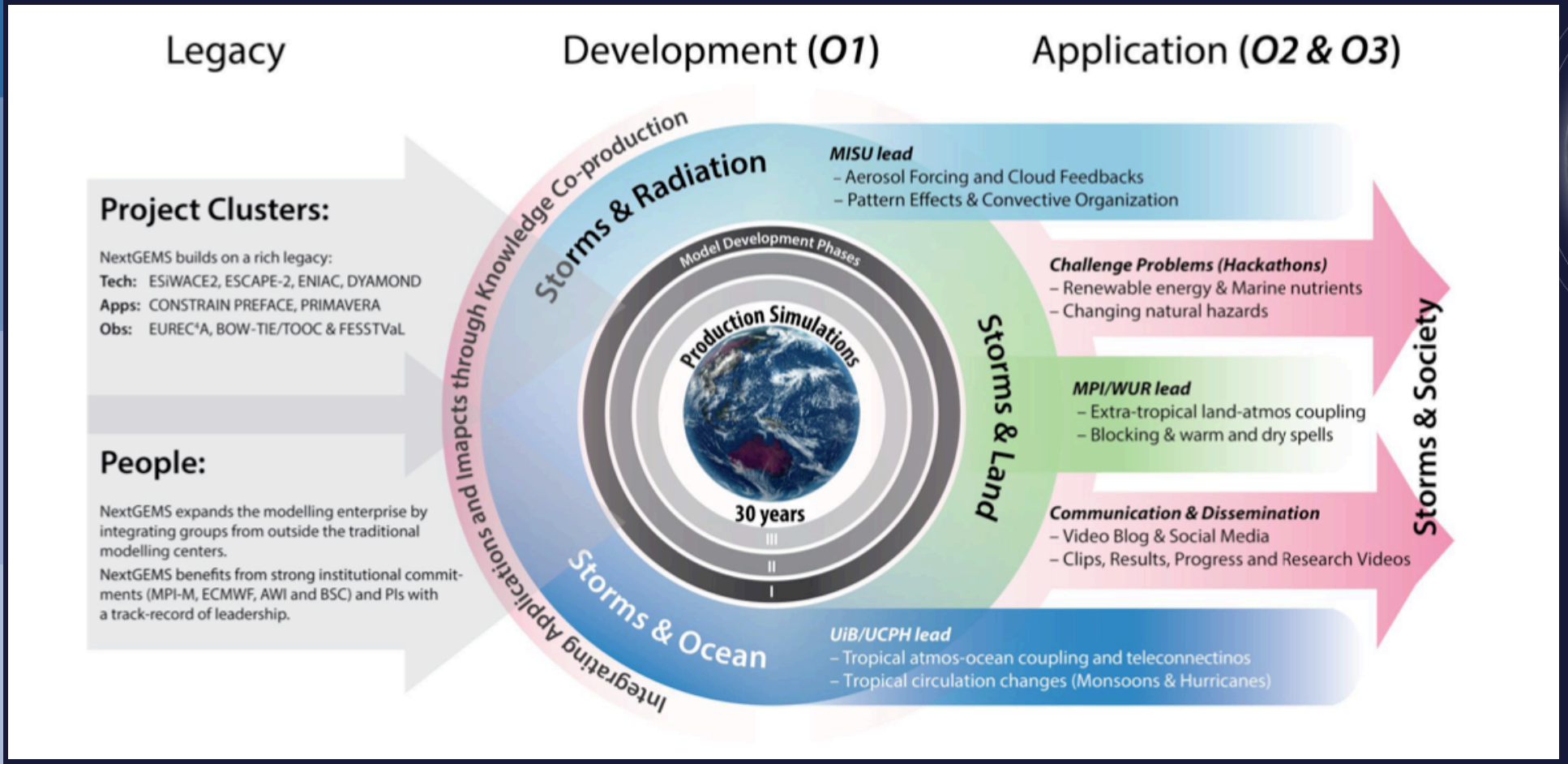
Aleuten Low Pressure System

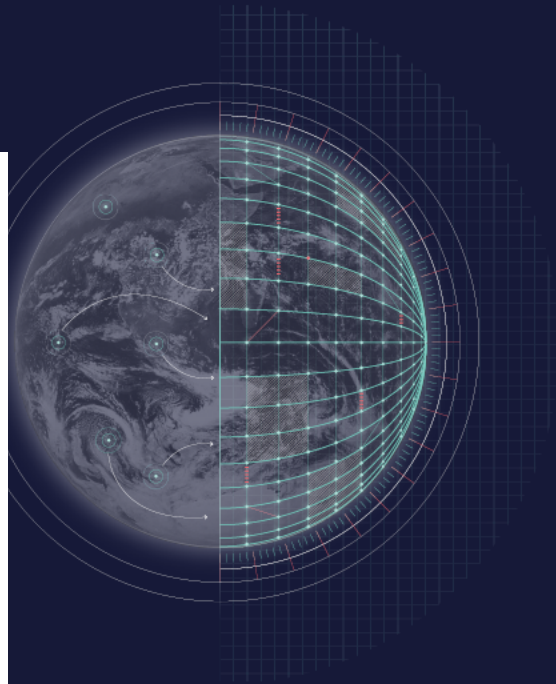
AWI FESOM2 team
Animation: Nikolay Koldunov (AWI)

A7

1950-01-01

Climate projection at storm-resolving scales





Stevens et al 2019, 2021; Bjorn Stevens, Irina Sandu et al H2020 funded nextGEMS project

Uncovering surprises within the climate system…

Conclusions

- Routine global km-scale data assimilation and prediction of the coupled Earth System is within reach
- Big data handling, unsupervised learning, and near-real time interaction with km-scale global Earth System data provide unprecedented opportunities

"Our bigger vision is a near-real-time digital twin of our planet, particularly the planet's surface, which opens up a trillion use cases where traditional photogrammetry like a Google Earth or what Apple Maps is doing is not helping because those are just simplified for photos clued on simple geometrical structures"

Quoting CEO Michael Putz of Blackshark.ai in an interview about their work on MS FlightSimulator2020

https://techcrunch.com/2020/08/17/

How the EC's DestinE programme transforms environmental policy making – Digital twins as a step-change for Earth-system modelling and data assimilation

ECMWF

Acknowledgements

- The work benefitted from close collaboration between high-resolution simulation model benchmarking and advanced methodologies presently being developed for heterogeneous high-performance computing platforms at ECMWF in the *ESCAPE-2* (No. 800897), *MAESTRO* (No. 801101), *EuroEXA* (No. 754337), and *ESiWACE-2* (No. 823988) projects funded by the ***European Union's Horizon 2020*** future and emerging technologies and the research and innovation programmes.

- EarthCARE work was partially supported by the ***ESA funded*** project, Operational Assimilation of Space-borne Radar and Lidar observations for Numerical Weather Prediction (4000116891/16/NL/LvH) and the follow-on PEARL Cloud - Preparation for EarthCARE Assimilation of Radar and Lidar Cloud Observations - ESA ESTEC contract (4000128669/19/NL/CT).

- This research used resources of the ***Oak Ridge Leadership Computing Facility***, which is a DOE office of Science User Facility supported under contract DE-AC05-00OR22725

- Access to the ***CSCS PizDaint*** was kindly facilitated by Thomas Schulthess and Maria-Grazia Giuffreda

- Thanks to ***ECMWF staff*** and many ***international collaborations*** who directly or indirectly contributed to this presentation.