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Center**

Centro Nacional de Supercomputación

Weather and Climate HPC across scales

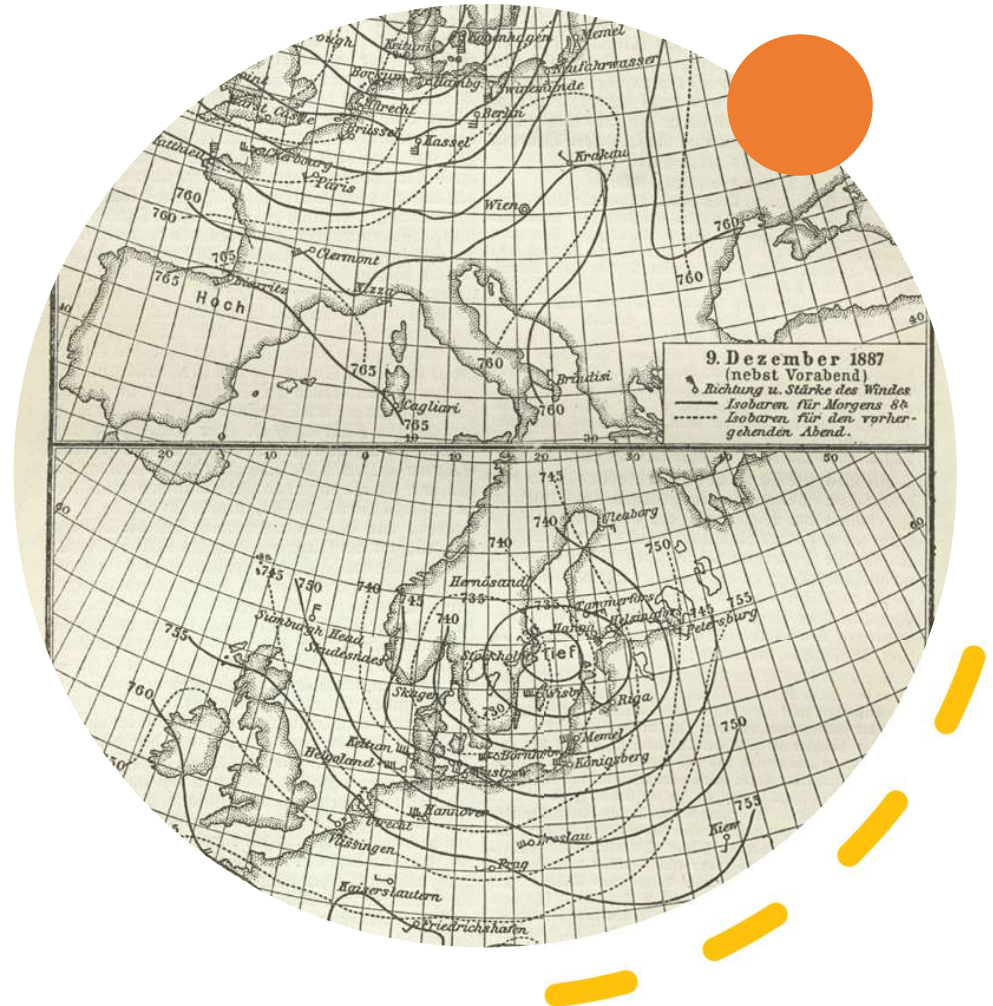
Luka Ilić

21/05/2025

EuroCC4SEE Workshop/Palata nauke, Beograd, Srbija

outline

- a little bit of history
- operational weather forecasting in different scenarios
 - meteorological service NWP
 - private sector
 - research
 - experimental campaigns
- research in weather and climate
 - addressing uncertainty
 - increased complexity
 - digital twins
 - ai
- weather map of europe, december 10, 1887



Weather Forecasting Factory

- Lewis FRY RICHARDSON (1881 –1953)
 - use LAWS OF PHYSICS
 - AND a FORECASTING FACTORY
 - NUMERICALLY UNSTABLE RESULTS BUT ON THE RIGHT TRACK
-
- ARTIST'S VISION OF a "Weather Forecasting Factory" BY STEPHEN CONLIN, 1986.



CONTEMPORARY NUMERICAL WEATHER PREDICTION

eniac

THE ENIAC FORECASTS

A Re-creation

BY PETER LYNCH

NCEP-NCAR reanalyses help show that four historic forecasts made in 1950 with a pioneering electronic computer all had some predictive skill and, with a minor modification, might have been still better.



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1

$$\frac{Du}{Dt} - f_r v + f_\phi w - \frac{uv \tan \phi}{r} + \frac{uw}{r} + \frac{c_p \theta_v}{r \cos \phi} \frac{\partial \Pi}{\partial \lambda} = P^u, \quad (3.3)$$

$$\frac{Dv}{Dt} + f_r u - f_\lambda w + \frac{u^2 \tan \phi}{r} + \frac{vw}{r} + \frac{c_p \theta_v}{r} \frac{\partial \Pi}{\partial \phi} = P^v, \quad (3.4)$$

$$\frac{Dw}{Dt} - f_\phi u + f_\lambda v - \frac{(u^2 + v^2)}{r} + g + c_p \theta_v \frac{\partial \Pi}{\partial r} = P^w, \quad (3.5)$$

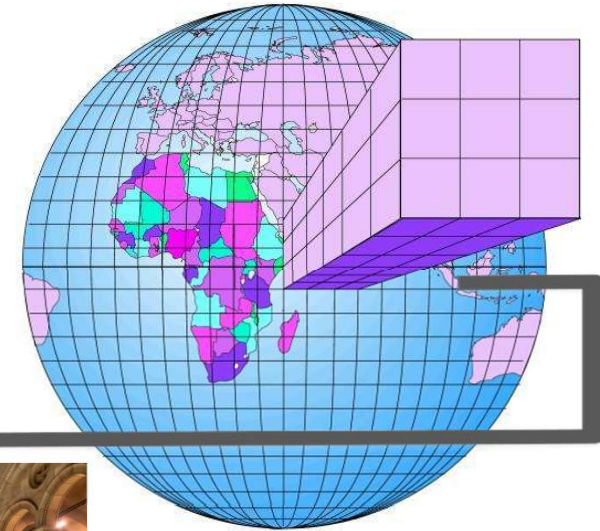
where the P terms are the tendencies from the physics parametrizations and for most applications P^w is set to zero. The material derivative is given by

$$\frac{D}{Dt} \equiv \frac{\partial}{\partial t} + \frac{u}{r \cos \phi} \frac{\partial}{\partial \lambda} + \frac{v}{r} \frac{\partial}{\partial \phi} + w \frac{\partial}{\partial r}. \quad (3.6)$$

When the coordinate poles are coincident with the geographical poles, the Coriolis terms are $(f_\lambda, f_\phi, f_r) = (0, 2\Omega \cos \phi, 2\Omega \sin \phi)$, where Ω is the Earth's angular speed

2

$$\left(\frac{\partial u}{\partial x} \right) \approx \frac{u_{i+1} - u_i}{\Delta x}$$



vdj — vdj@billa:~/carpatclim — ssh — vdj@147.91.68.195 — 109x44

Program test

```
real, parameter :: nbo=50., sbo=41.9, ebo=27, wbo=16.2, dx=0.1, dy=0.1, idxgm=6913
integer, parameter :: im=1.5+(ebo-wbo)/dx, jm=1.5+(nbo-sbo)/dy
integer, parameter :: iym=50, imm=12, iyst=1961
real, dimension (im,jm) :: rr
integer, dimension (idxgm) :: idxg,idxf,gco,iloc,jloc
real, dimension (idxgm) :: rr1D,glon,glat
integer, dimension (imm) :: mnd
character*5 lyr,adum
```

```
data mnd/31,28,31,30,31,30,31,31,31,30,31,30,31/
```

```
print *, 'im,jm,im+jm', im,jm,im+jm
open(12,file='RR/PredtandfildGrid.dat')
read(12,*) adum
do ix=1,idxgm
read(12,*) idxg(ix),glon(ix),glat(ix),gco(ix)
enddo
```

```
ix=idxgm
print *, idxg(ix),glon(ix),glat(ix),gco(ix)
```

```
do ix=1,idxgm
iloc(ix)=1.5+((glon(ix)-wbo)/dx)
jloc(ix)=1.5+((glat(ix)-sbo)/dy)
write (99,*) glon(ix),glat(ix),iloc(ix),jloc(ix)
enddo
```

```
open(13,file='grd/RR_carpath.grd',access='direct',recl=im+jm)
open(14,file='grd/RR_carpathctl')
```

```
open(20,file='RR/CARPATGRID_PREC_D.ser')
read(20,*) (idxf(i),i=1,idxgm)
```

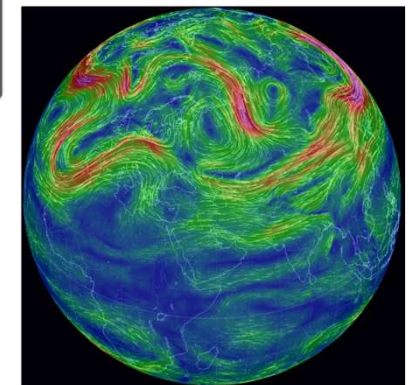
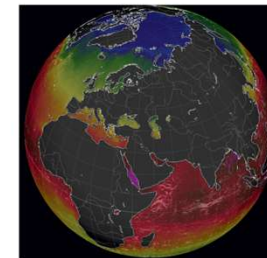
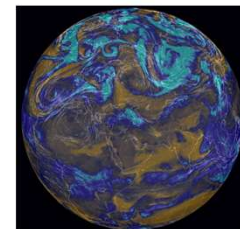
```
ir=0
do iy=1,iym
iyear=iyst+iy-1
iry=0
lyr='NLEAP'
do imo=1,imm
mnd(2)=28
if(mod(iyear,4).eq.0.and.iyear.ne.2100) mnd(2)=29
```

3

4



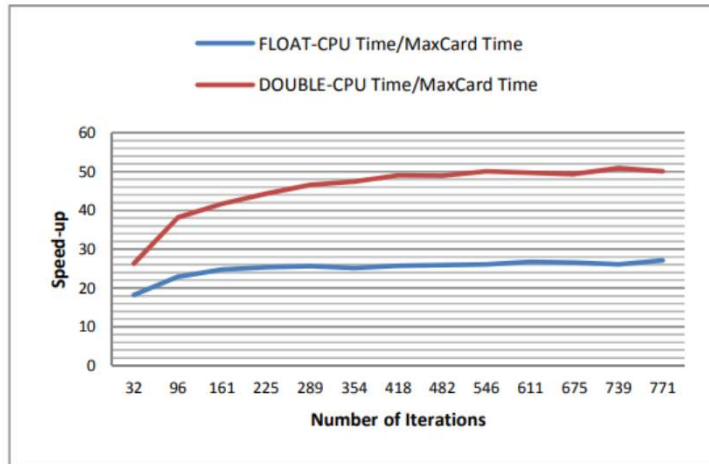
5



south environment and weather agency (sewa)

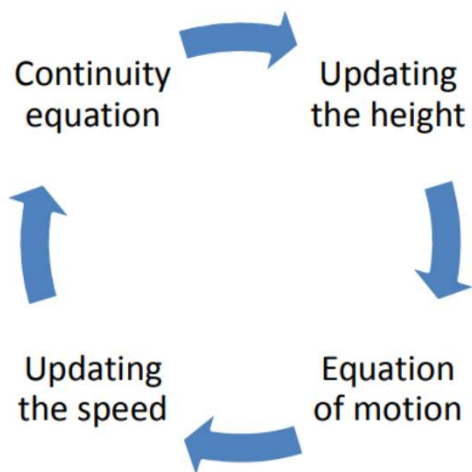
- ~25 years IN Business
- IN-House BUILT Beowulf CLUSTER
- DEDICATED servers
- TAILORED WEATHER PRODUCTS





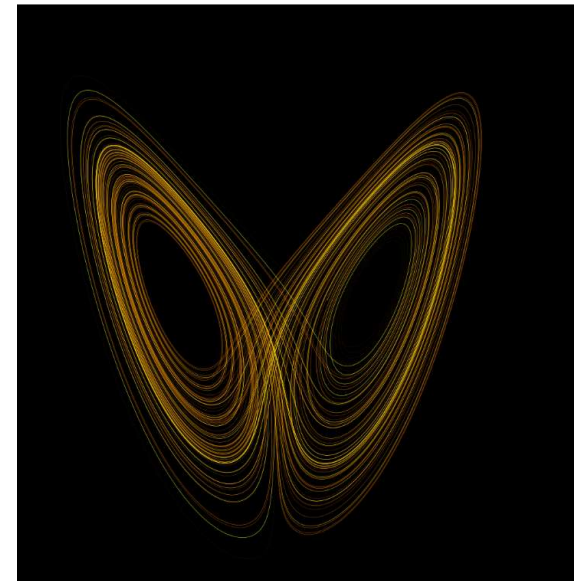
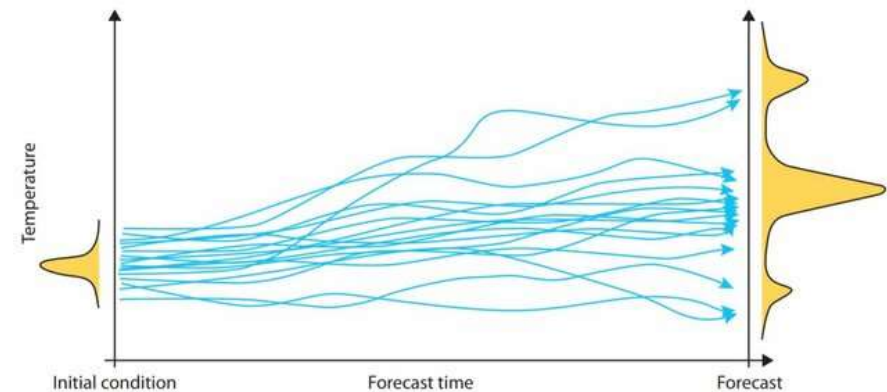
exploring the accelerator option — dataflow

- meteos/maxeler/school of electrical engineering, university of Belgrade
- PORTING a system of shallow water equations
- a rotating rectangular pan filled with water
- strong dependence on data inputs
- (IVKOVIĆ et al, 2013)



CHaOS IN THE aTmosPHeRe

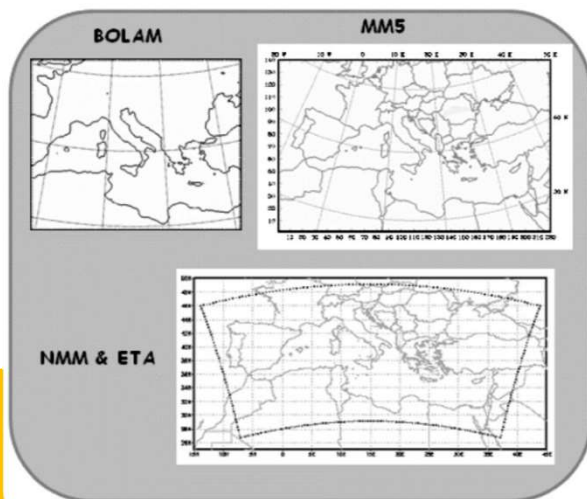
- deTeRMINISTIC NON-PeRIODIC FLOW (LoRENZ, 1963)
- PRedICTaBILITy of aTmosPHeRIC FLOW
- eNseMBlE PRedICTION
- vaRIaBlE INITIAL CONDITIONS
- sPaGHettI PlOt FRom GRÖNQVIST et al, 2019



see-GRID-SCI FP7 PRoJect



- Institute of PHYSICS BeLGRade (IPB) / seWa / National OBSERVATORY of aTHEns (NOA)
- multi model multi analysis ensemble ON THE GRID (KotRONI et al. 2009)
- DIStRIButed HPC INFRAstruCTure (Balaž et al, 2011)



Can We add a few
more equations?

Dust Regional atmospheric model (DREAM)

NIČKOVIĆ et al, 1994

Radiation Interactions

Ice Nucleation

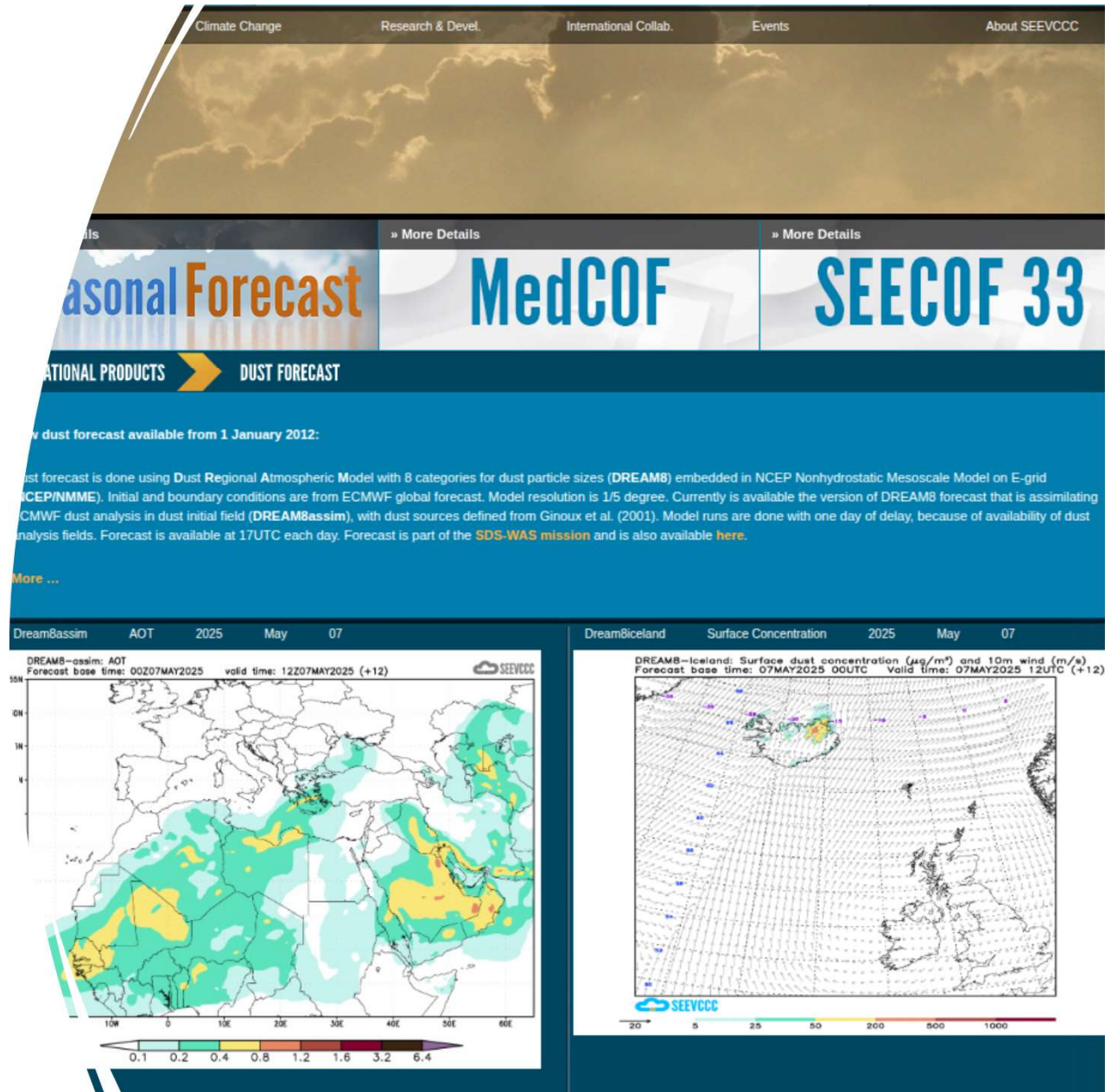
alGae BLoom

HeALTH IMPACTs



RePuBLIC HYDrometeoROLOGICAL seRVICE of seRBia

- southEast euROpean vIRtual CLimate CHAnGe CeNteR (seeVCCC)
 - sand AND dust storm wARning AND ADVISORY system (SDS-WAS)
 - wORLD meteOROLOGICAL ORGAnIZATIOn (WMO)
 - HIGH-LATITUDE dust - ICELAND



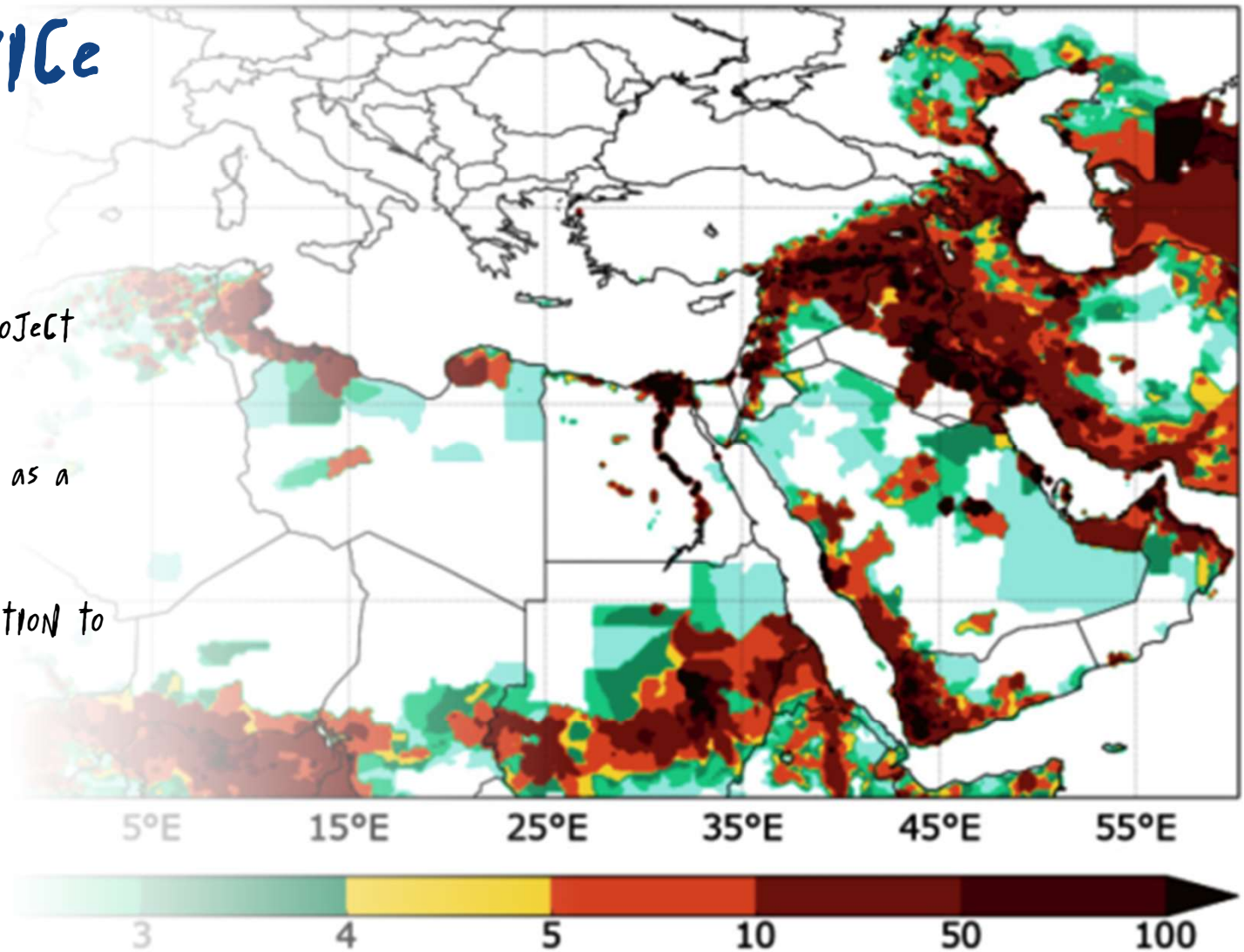
atmosPHeRIC ReseaRCH at IPB

- eNVIROnmentAL PHYSICS
LABORATORY
- sCIeNTIFIC COmPUTING
LABORATORY
- DReam model DEVELOPMENT
- DUST ReseaRCH
- oPERAtIONAL FOReCASTING
- LIDAR meASUREMENTS
- model VALIDAtION



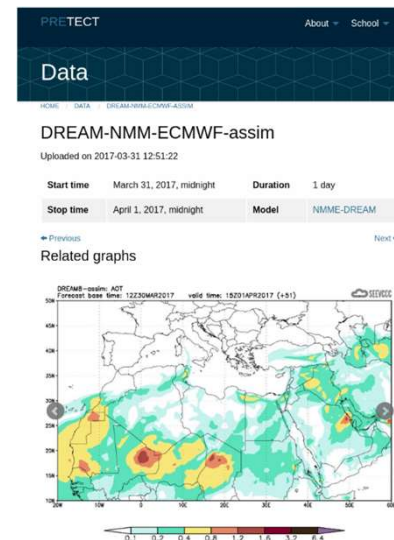
CLimate seRvIce at IPB

- VI-seem HORIZON 2020 PRoJect
(VUDRAGOVIC et al. 2018)
- CLImatOLOGICAL assessment as a
seRvIce
- use-Case of dust CONTRIBution to
PM_{2.5} POLLution



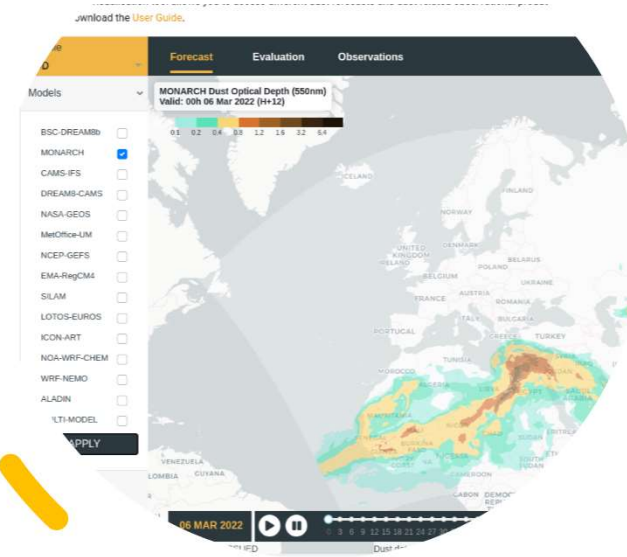
Research and Weather service COLLAB.

- operational and Research
- even more complexity
 - mineralogy of dust
 - ice nucleating particle concentrations
- NIČKOVIĆ et al 2012, 2016, 2021;
ILIĆ et al 2022
- PRE-TECT Campaign in Crete, April 2017



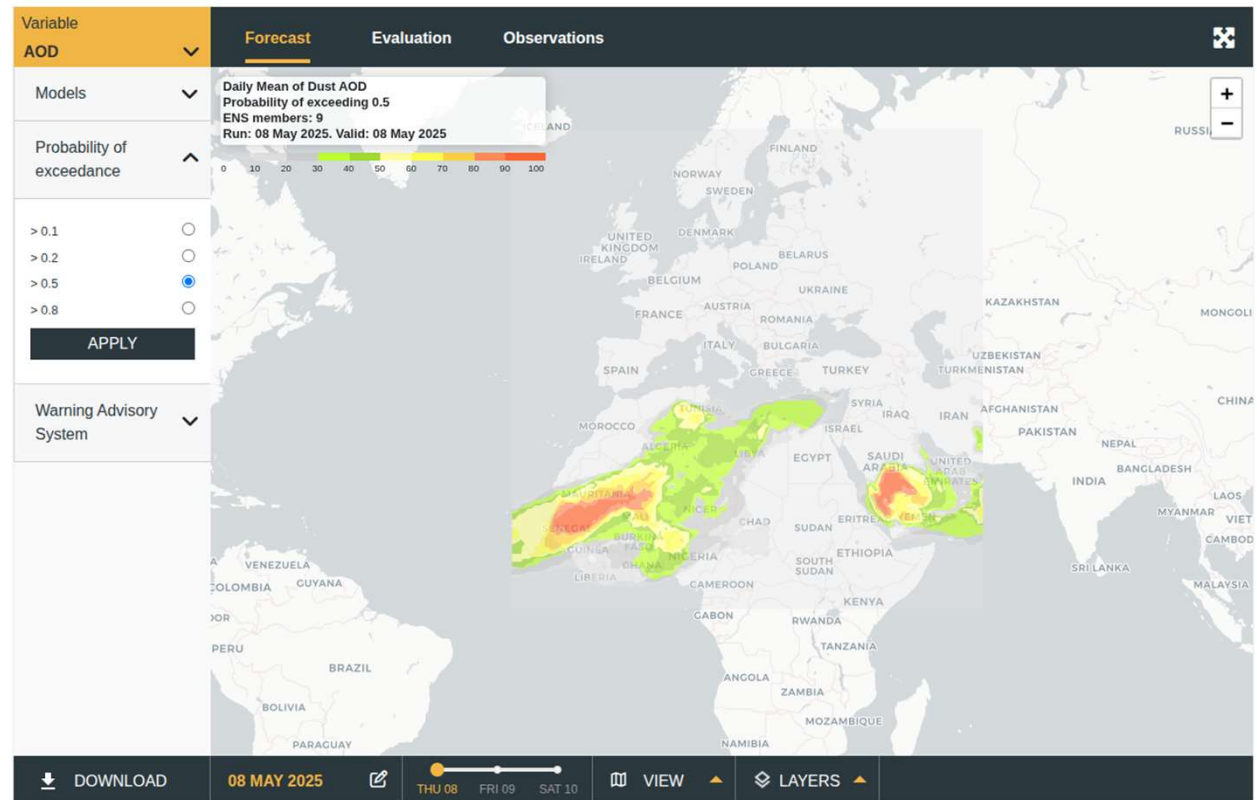
scaling—up even further

- BARCELONA SUPERCOMPUTING CENTER (BSC)
- monARCH model (Klose et al, 2021)
- minERaLOGY (GONçALVES AGUIROS et al 2023)
- DUST AND CHEMISTRY (sousse et al, 2025)
- RADIATION INTERACTIONS (OBISO et al, 2024)



BACK to SDS—Was

- complex models, atmosphere and aerosols
- multi-model ensemble contributions from several regional centers

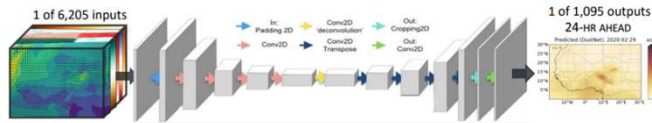
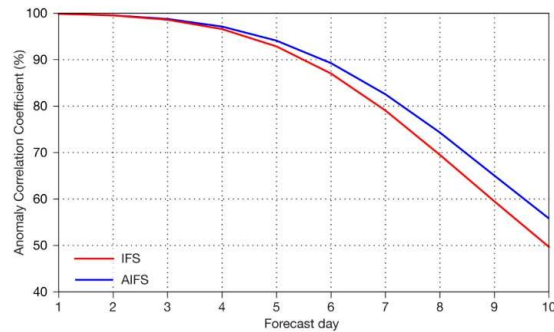




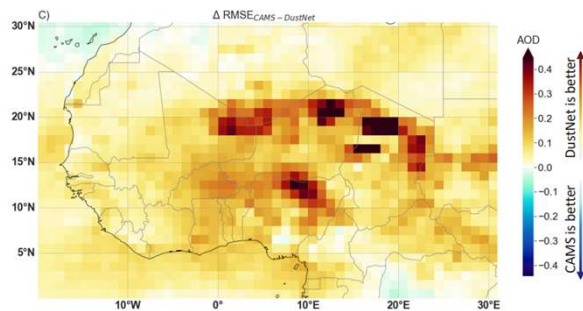
DIGITAL TWINS

- eCMWF / esa / eumetsat — the DESTINATION earth INITIATIVE
- the FIRST PRE-exascale supercomputers IN europe
- OPERATIONAL PRODUCTION OF GLOBAL CLIMATE PROJECTIONS
- GLOBALLY CONSISTENT earth system AND IMPACT sector INFORMATION
- FROM GLOBAL to LOCAL scales

MACHINE LEARNING AND AI IN WEATHER AND CLIMATE



- speed
- efficiency
- skill
- (still) dependent on physics-based models
- aifs: a new ECMWF forecasting system (Lang et al, 2024)
- DustNet (Nowak et al, 2024)



outlook on HPC IN Weather and Climate

- Provide space to improve on Weather and Climate Research
- Increased complexity of the models, coupling
- Addressing uncertainties
- Faster and cheaper operational forecasts
- availability of models as a service
- Predictability



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THANK you!x

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Y UNIVERSIDADES



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la Unión Europea
NextGenerationEU



Plan de Recuperación,
Transformación y
Resiliencia



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