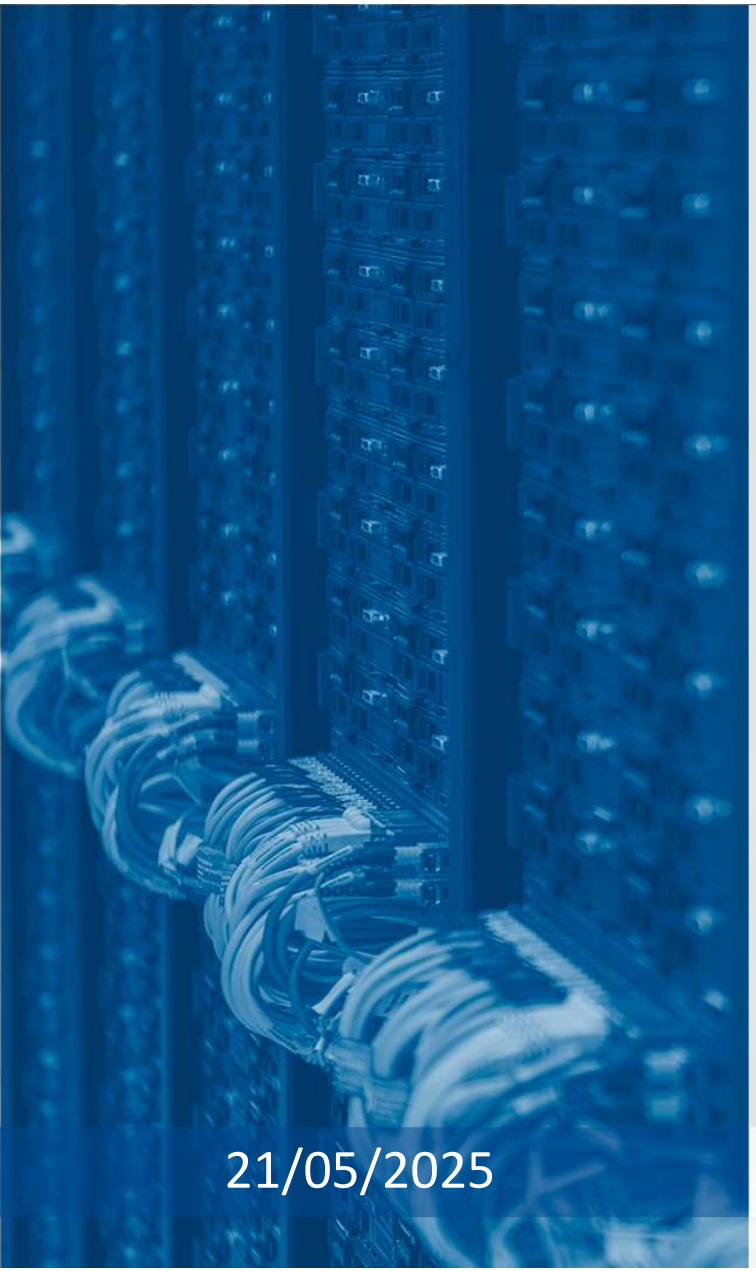


Barcelona Supercomputing Center
Centro Nacional de Supercomputación

WeaTHeR aND CLImate HPC aCRoss sCaLes

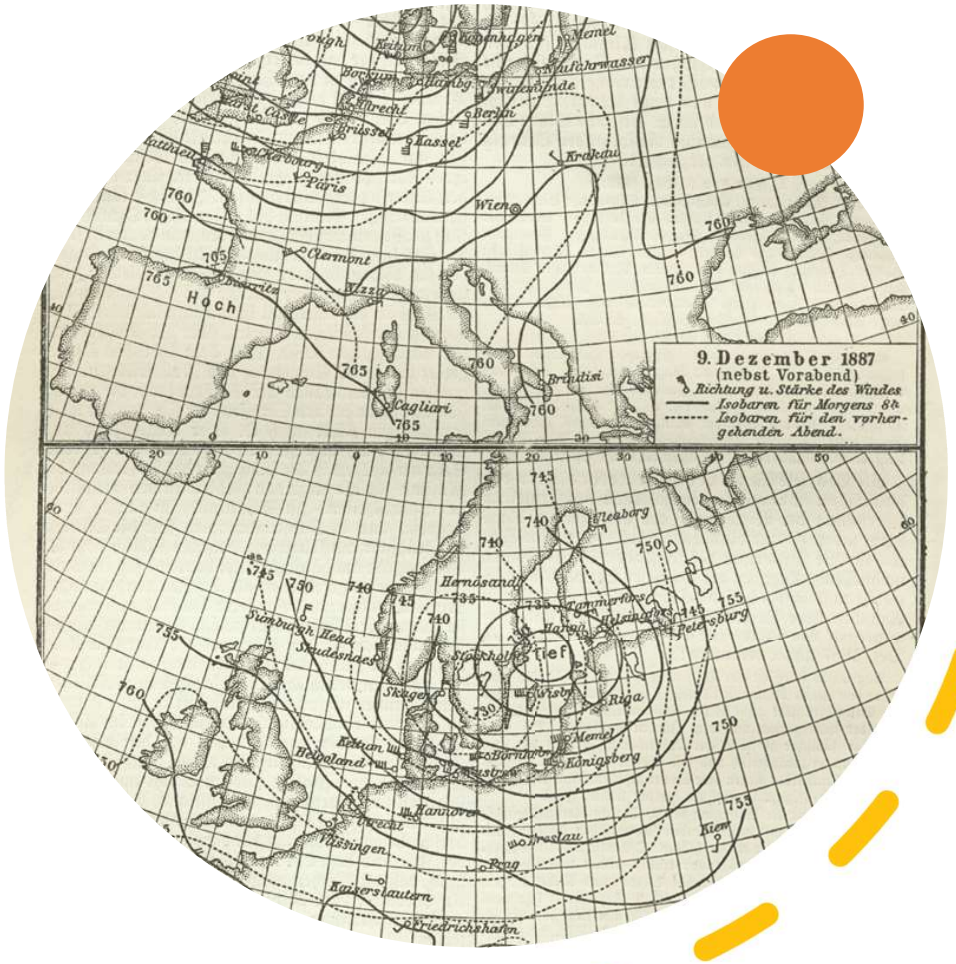
LuKa ILIĆ

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



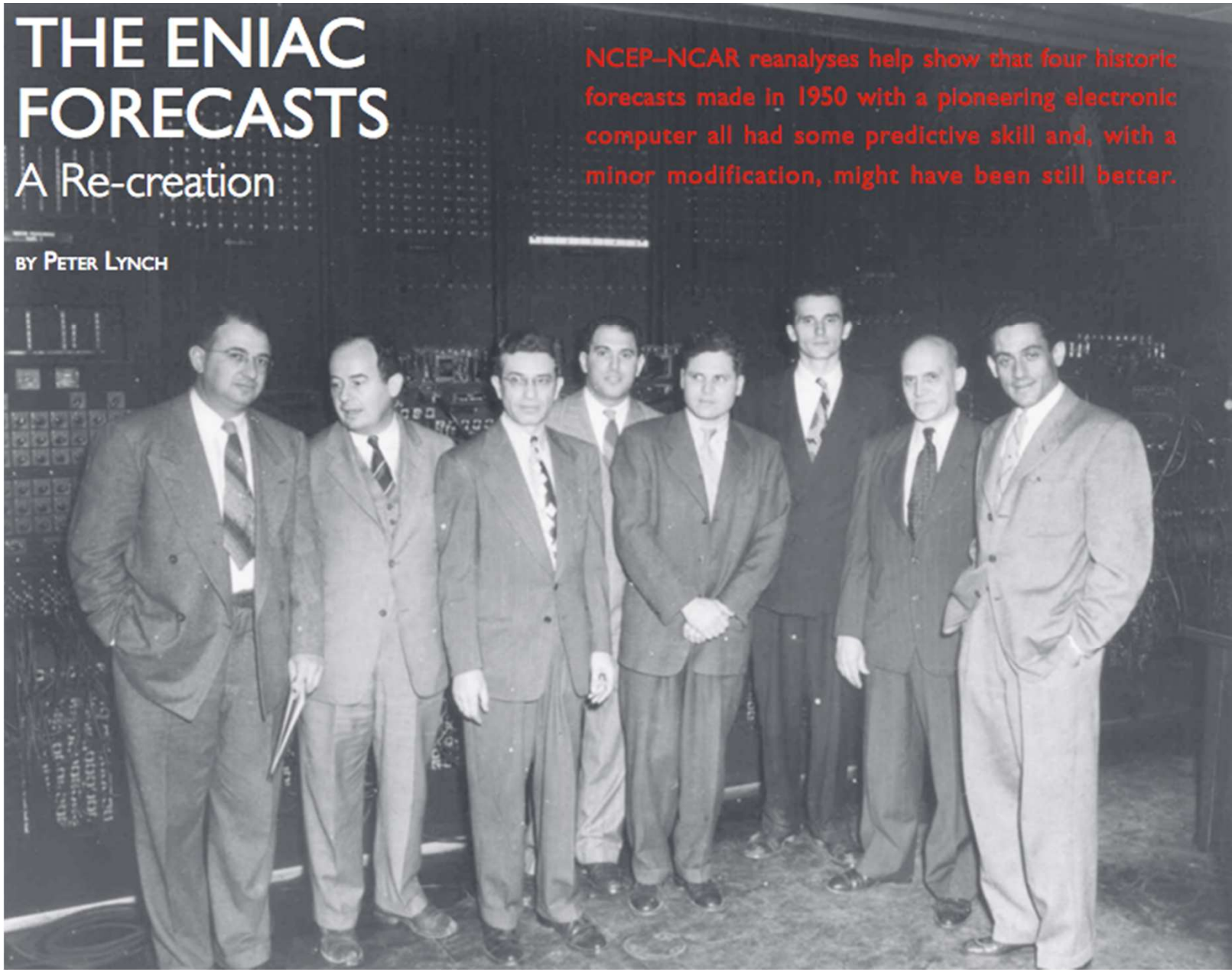
Weather Forecasting Factory

- 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



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1

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

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

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

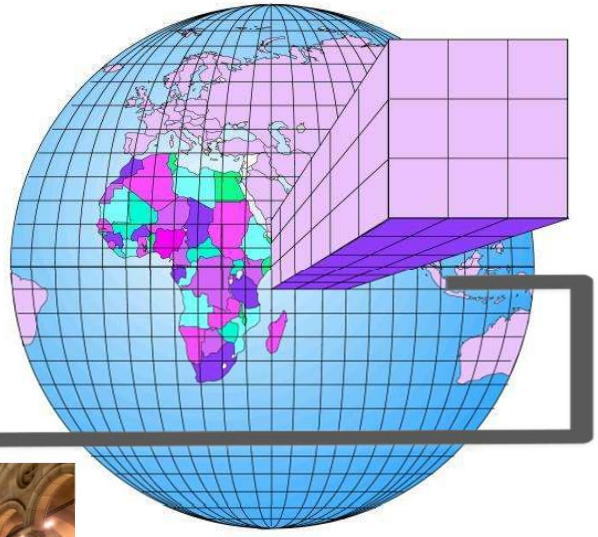
where the P terms are the tendencies from the physics parametrizations and for most applications P^w is set to zero. The material derivative is given by

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

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

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

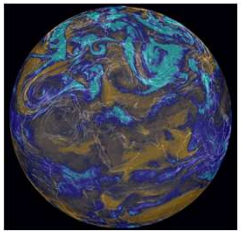


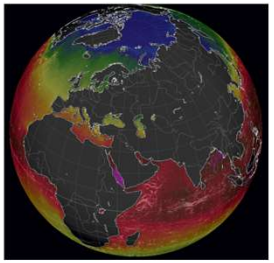
3

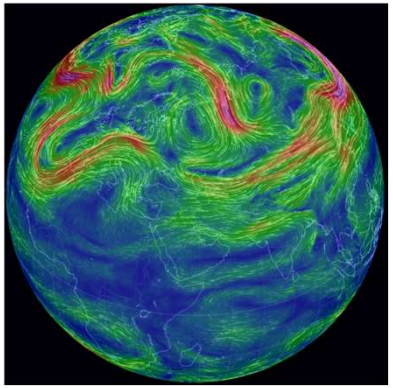
```
program test

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/31,28,31,30,31,30,31,31,30,31,30,31/

print *, 'im,jm,im*jm',im,jm,im*jm
open(12,file='RR/PredtandfilaGrid.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_carpath.ctl')

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
```

4

5



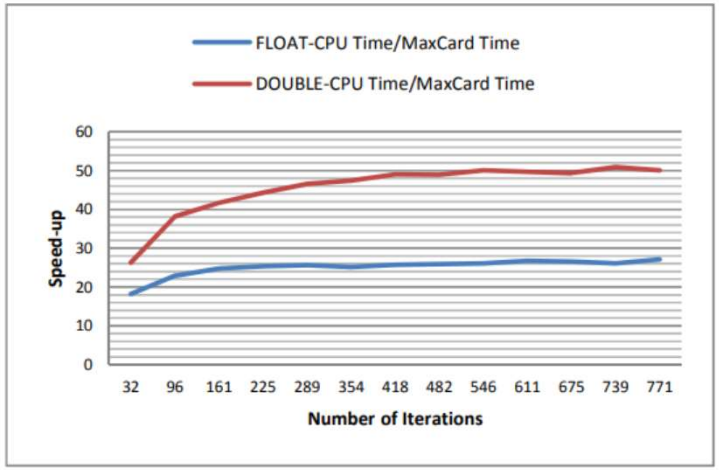


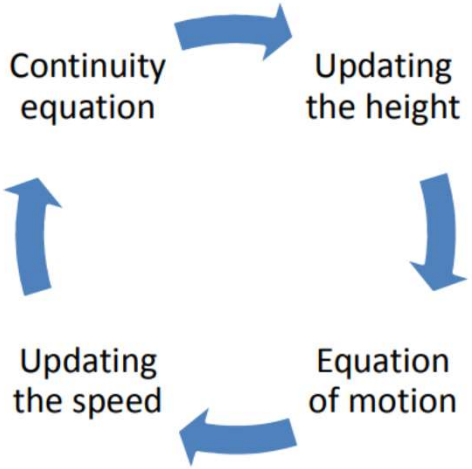


slide by Vladimir Đurđević, University of Belgrade

South Environment and Weather Agency (SEWA)

- ~25 years in business
- In-house built Beowulf cluster
- Dedicated servers
- Tailored weather products



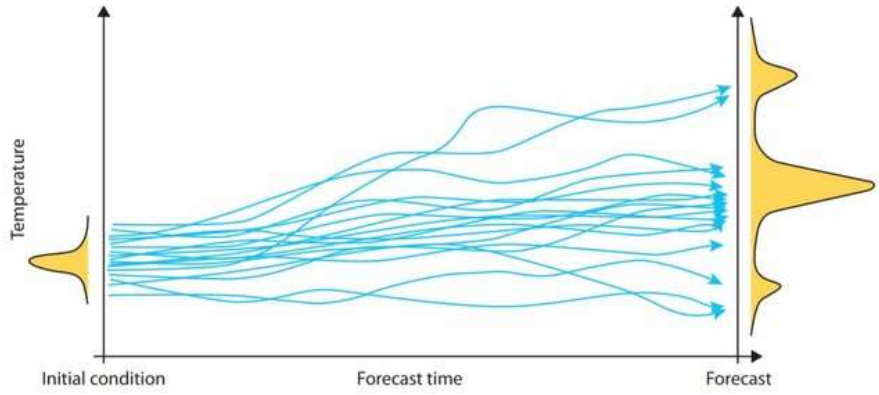


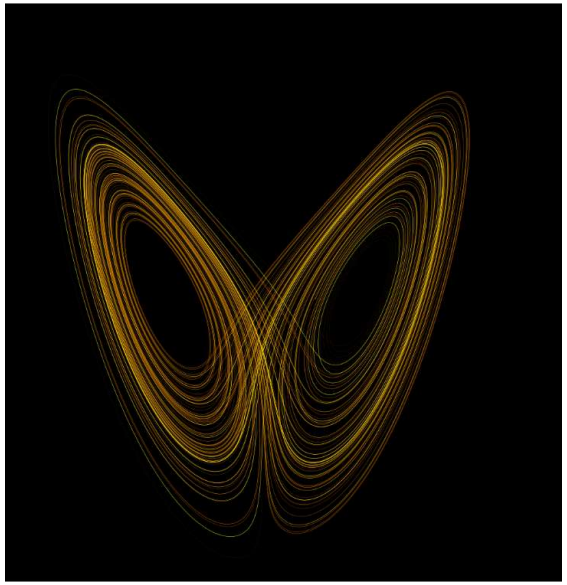
Exploring the Accelerator Option – DataFlow

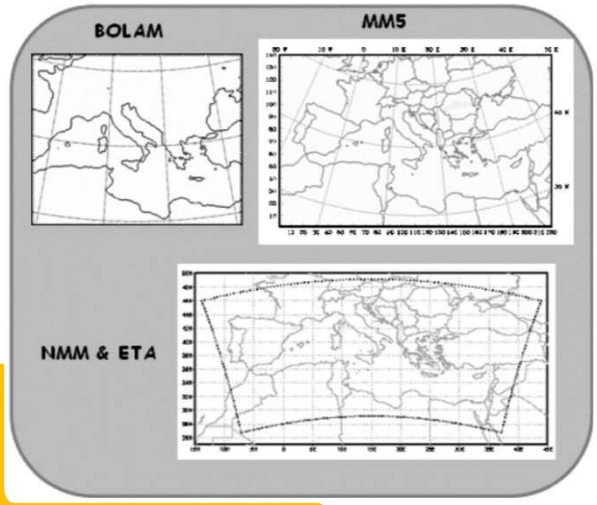
- Meteos/MaxeleR/School of eLeCTRICaL eNGINeeRING, UNIVeRSITY OF BeLGaRDe
- PORTING a System of sHaLLOW WaTeR eQUaTIONS
- a ROTATING RECTANGULaR PaN FILLED WITH WaTeR
- STRONG DePeNDaNCe ON Data INPUTS
- (IVKOVIĆ et aL, 2013)

Chaos in the atmosphere

- deterministic non-periodic flow (Lorenz, 1963)
- predictability of atmospheric flow
- ensemble prediction
- variable initial conditions
- spaghetti plot from Grönquist 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)

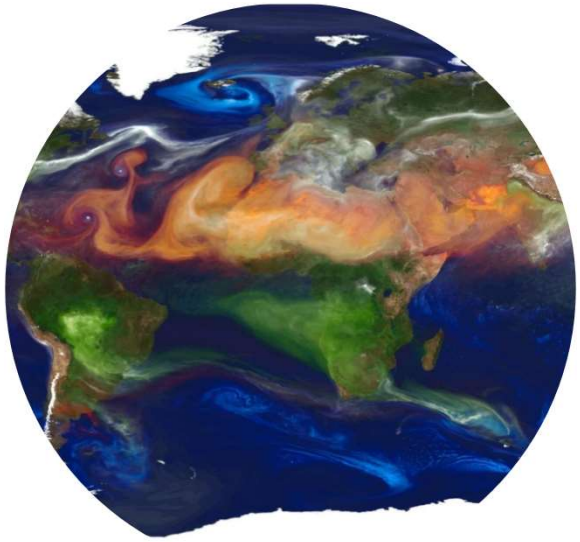
Ničković et al, 1994

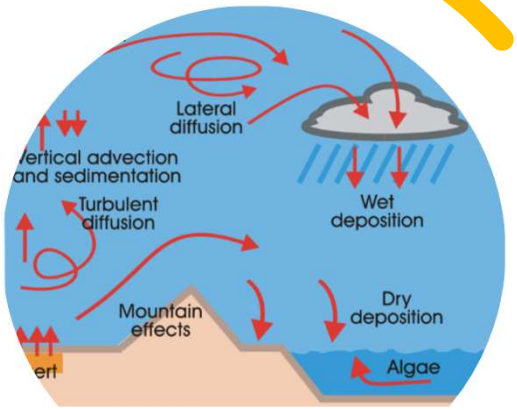
Radiation interactions

Ice nucleation

algae bloom

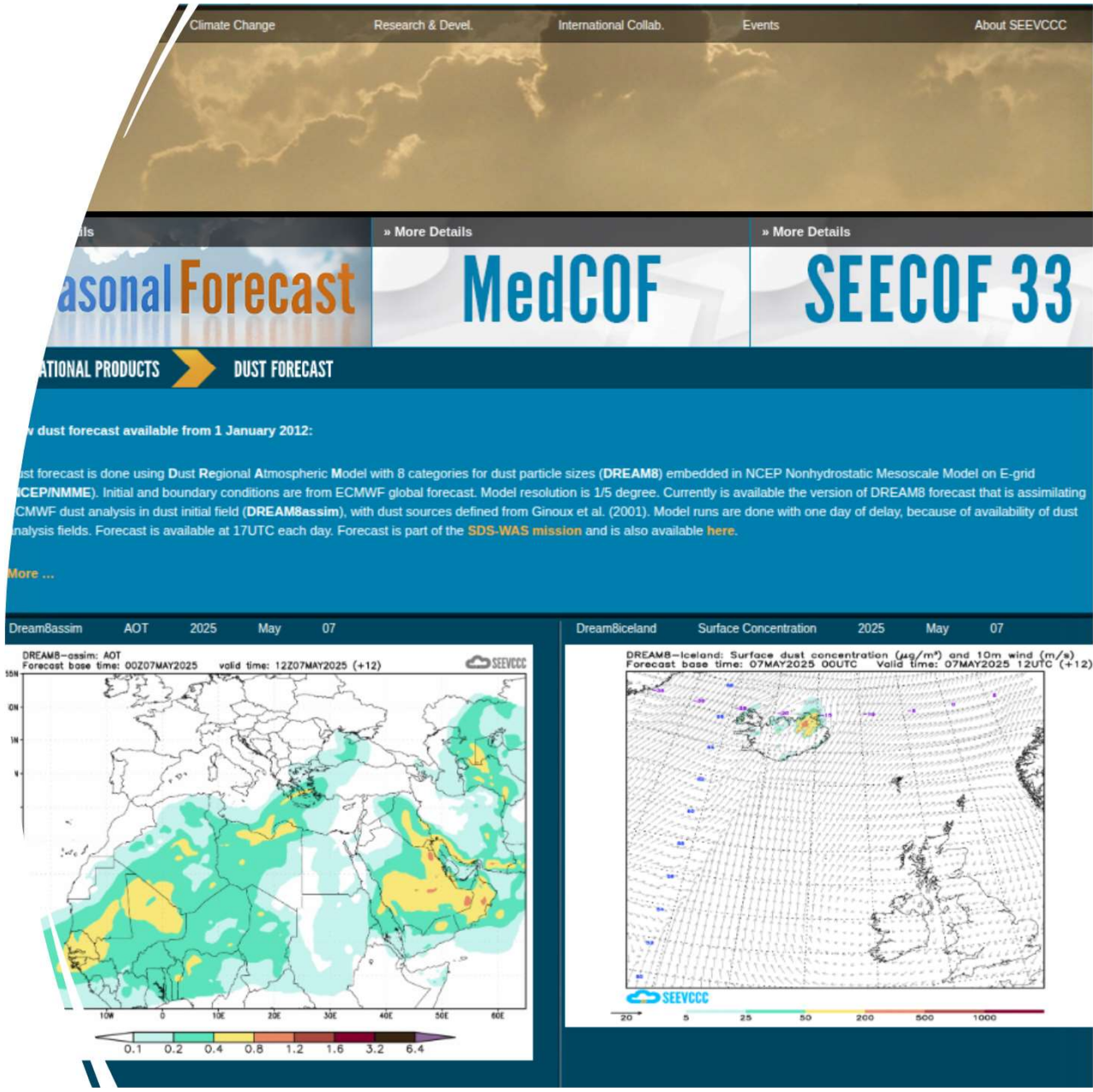
Health impacts





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



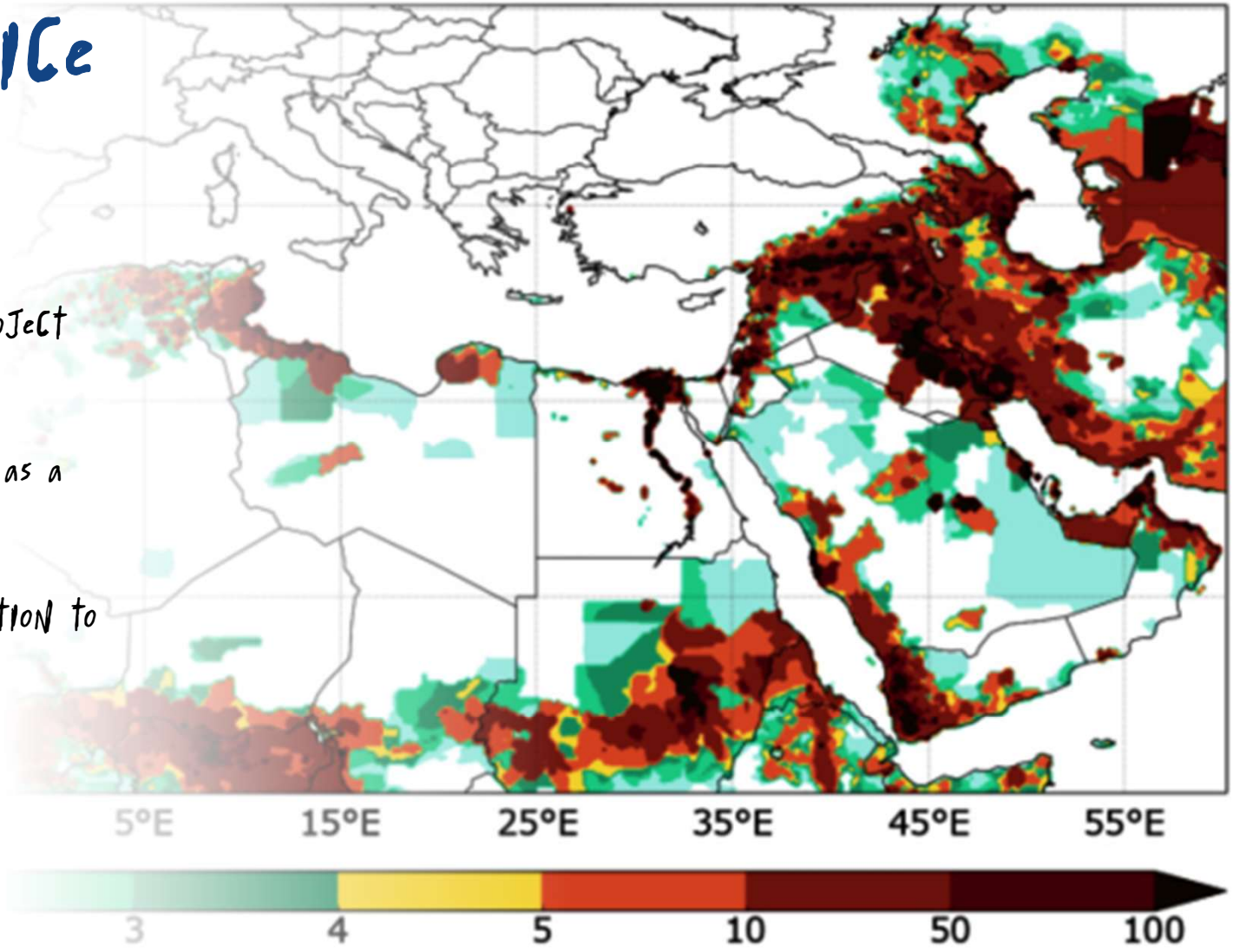
atmospheric research at IPB

- environmental physics laboratory
- scientific computing laboratory

- dream model development
- dust research
- operational forecasting
- lidar measurements
- model validation

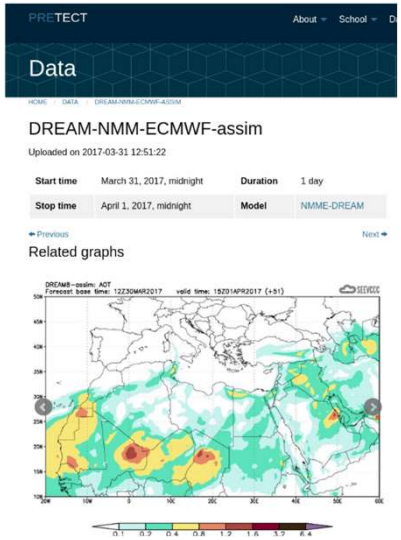
CLimate seRvICe at IPB

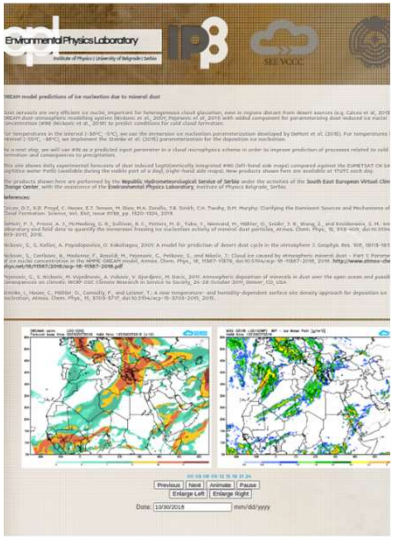
- VI-seem HoRIZoN 2020 PRoJeCt (VUDRAGOVIĆ et aL. 2018)
- CLImatoLoGICaL assessmeNt as a seRvICe
- use-Case of DUST CoNTRIBUTION to Pm2.5 PoLLUTION



ResearCH and Weather service CollaB.

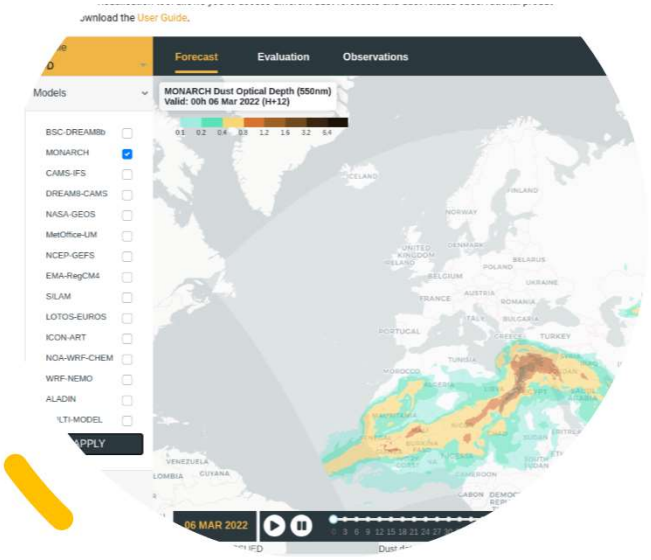
- operational and research
- even more complexity
  - mineralogy of dust
  - ice nucleating particle concentrations
- Ničković et al 2012, 2016, 2021; Ilić et al 2022
- PRe-tect campaign in Crete, april 2017

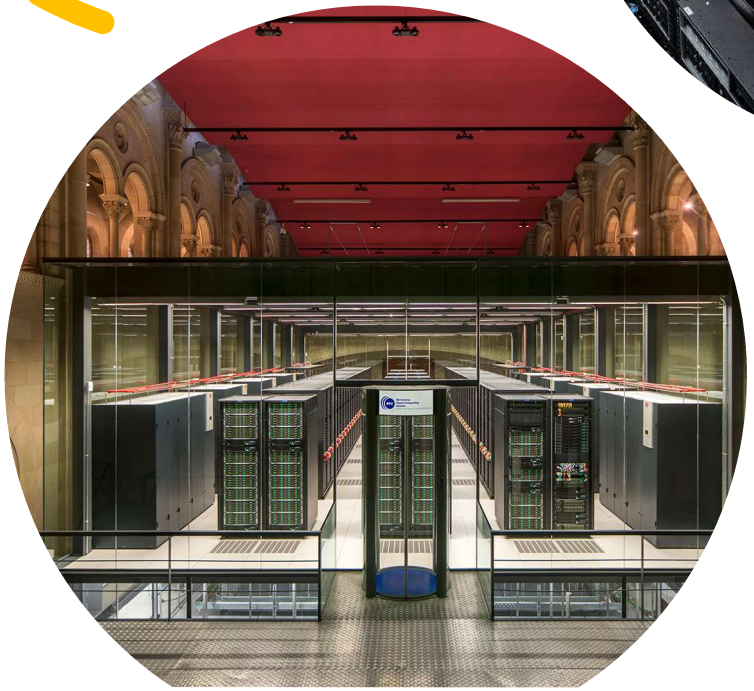




Scaling-up even further

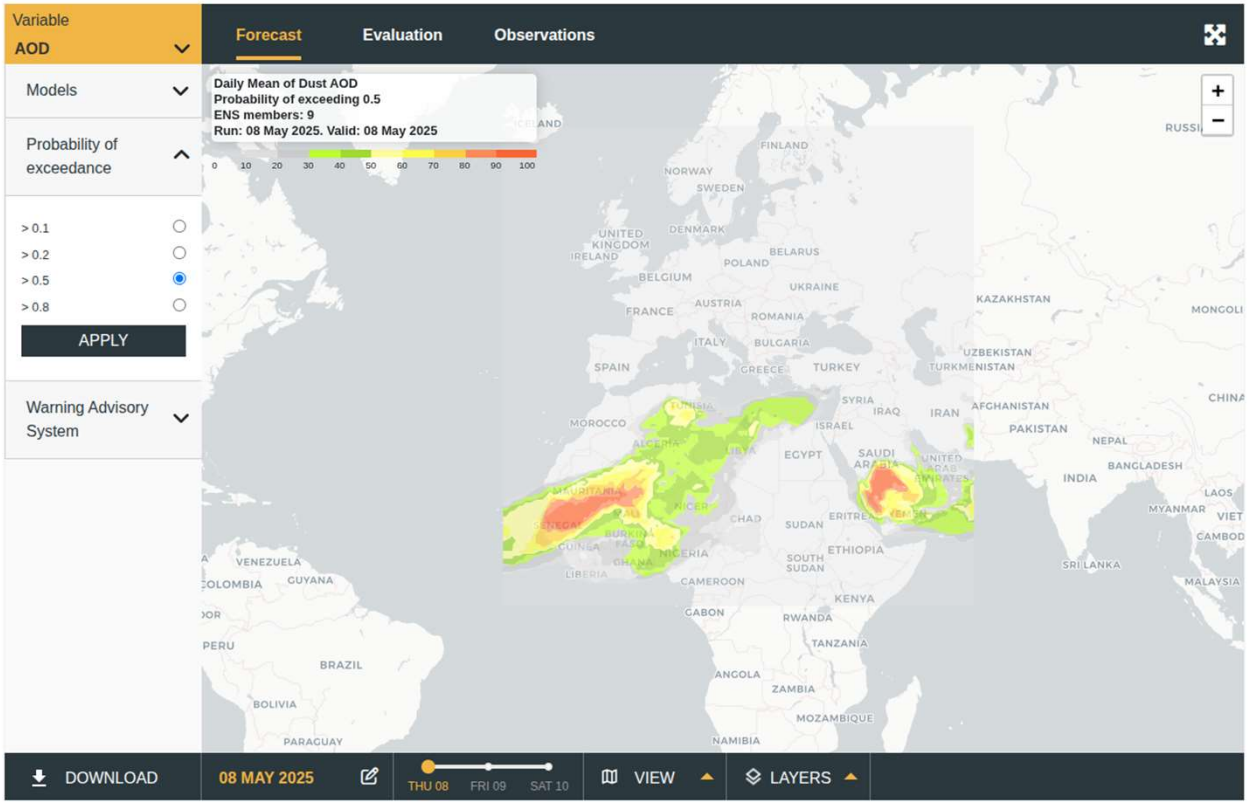
- Barcelona Supercomputing Center (BSC)
- MONARCH model (Klose et al, 2021)
- Mineralogy (Gonçalves Ageitos et al 2023)
- Dust and Chemistry (Sousse et al, 2025)
- Radiation interactions (Obiso et al, 2024)





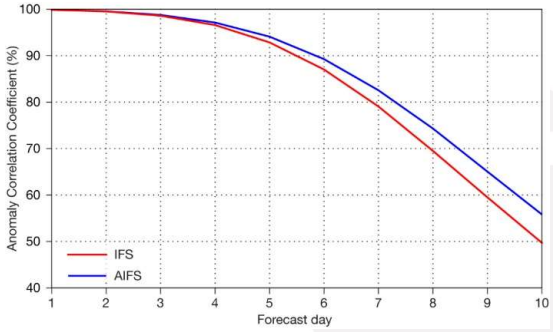
Back to SDS-WAS

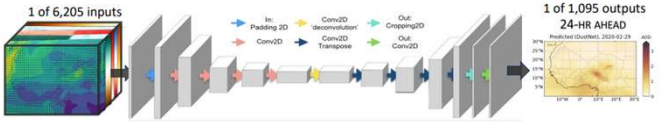
- Complex models, atmosphere and aerosols
- Multi-model ensemble contributions from several regional centers

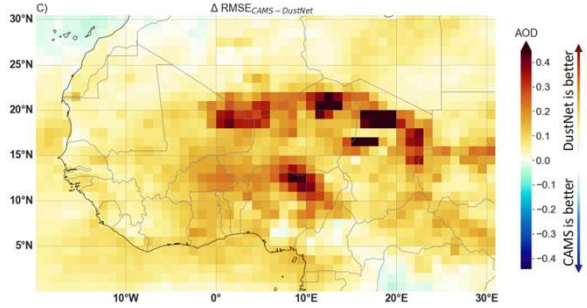


DIGITAL TWINS

- 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

Barcelona Supercomputing Center
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tHaNK You!

www.atmosphericdust.com

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