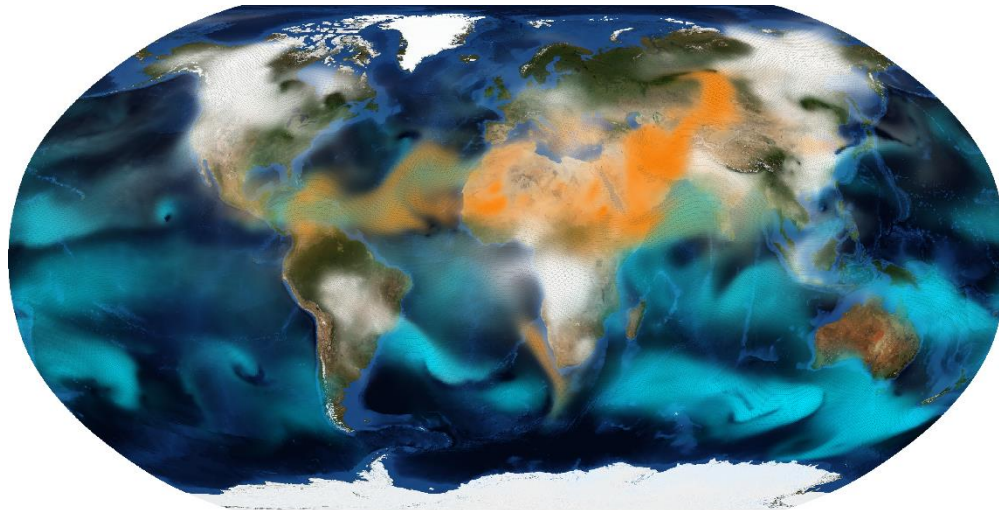




Simplified Prognostic Aerosol

D. Rieger & G. Zängl

ICON



NWP Configuration
Climatological aerosol –
cheap with known deficiencies

?



Full aerosol/chemistry
can be factor 2-4 in runtime

Currently Operational:

Tegen climatological aerosol

5 species: BC, OC, SO₄, dust, sea salt

AOD@550nm; vertical: exp. decay

Known Deficiencies:

From the 1990s → outdated!

No interaction with weather patterns

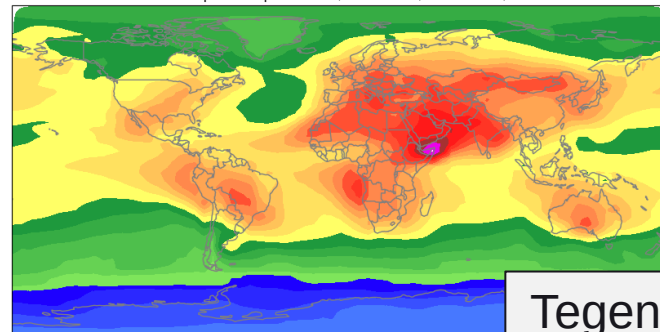
Wildfires missing

Low-hanging fruit?

Sophisticated schemes are expensive

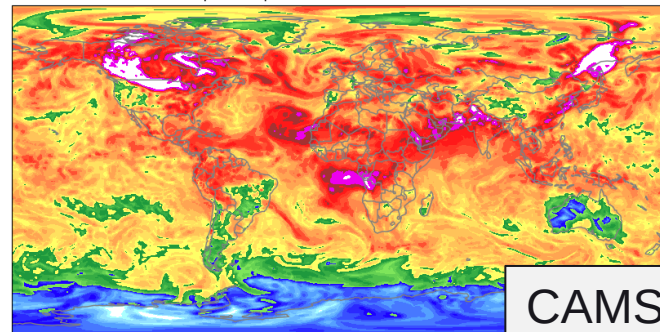
Can adding a minimum of complexity improve the forecasts without adding a major overhead (runtime/memory)?

2023071500 Total Aerosol Optical Depth 550nm, Min: 0.005, Max: 1.055, Median: 0.071



Tegen

2023071500 Total Aerosol Optical Depth 550nm, Min: 0.000, Max: 11.886, Med: 0.101

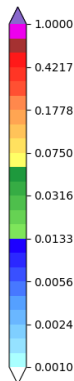
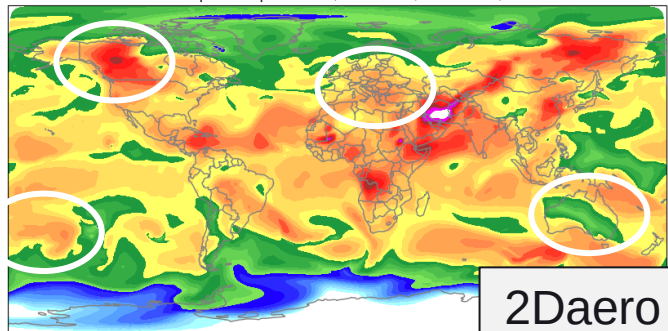


CAMS

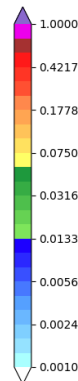
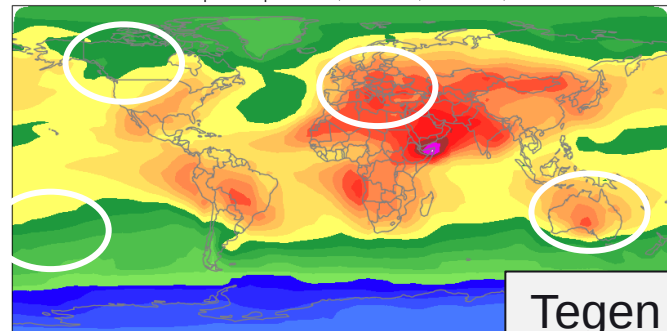
Copernicus Atmosphere Monitoring Service, 2020; Inness et al., 2019

prog2Daero: Anticipating the final result

2023071500 Total Aerosol Optical Depth 550nm, Min: 0.000, Max: 1.960, Median: 0.082



2023071500 Total Aerosol Optical Depth 550nm, Min: 0.005, Max: 1.055, Median: 0.071



Impact of weather patterns

clearly visible at many places

Wildfires are considered

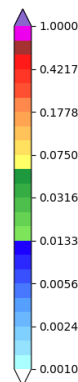
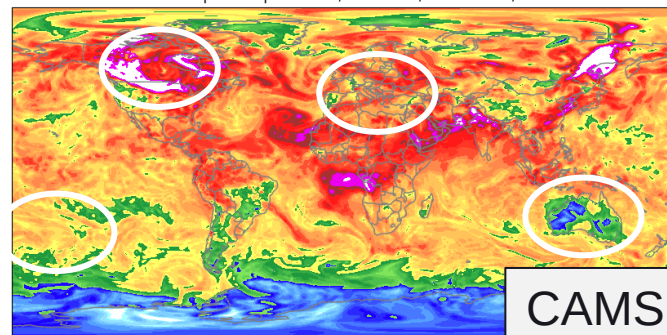
too weak, but significant step towards
the right direction

Up-to-date emissions

Systematic bias reduction for Europe

Radiation scores like smooth fields

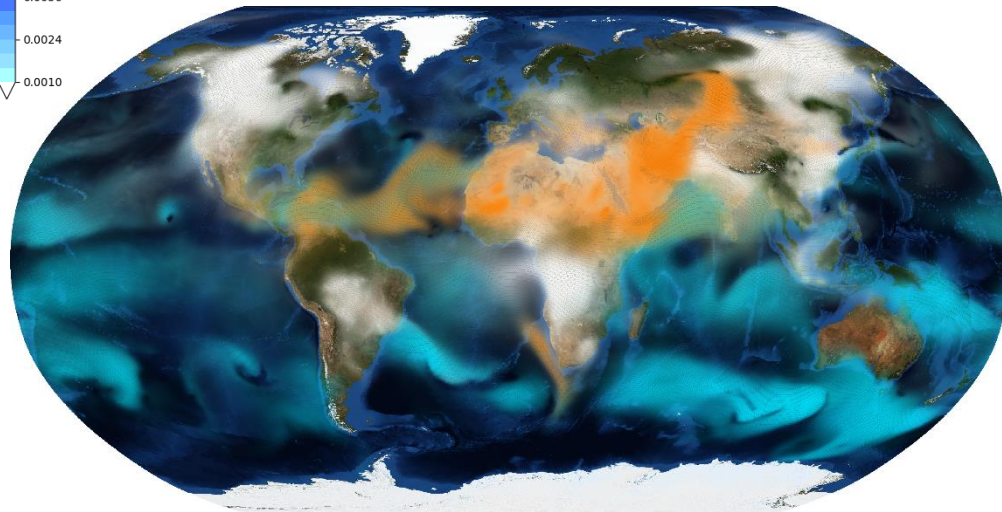
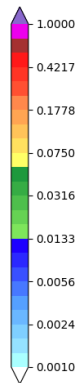
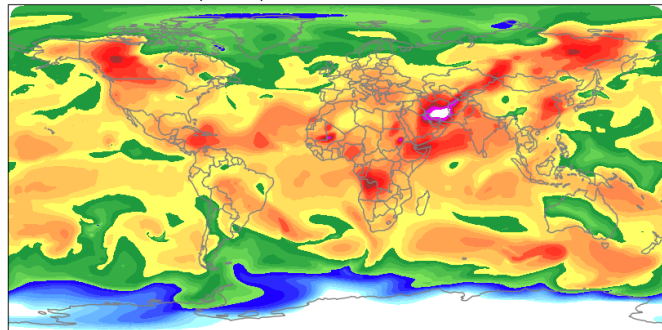
2023071500 Total Aerosol Optical Depth 550nm, Min: 0.000, Max: 11.886, Med: 0.101



Copernicus Atmosphere Monitoring Service, 2020; Inness et al., 2019

prog2Daero: Anticipating the final result

2023071500 Total Aerosol Optical Depth 550nm, Min: 0.000, Max: 1.960, Median: 0.082



Prognostic equation for 2D-AOD $\psi_j(x, y)$ (red: tuning parameters)

$$\frac{\partial \psi_j(x, y)}{\partial t} = \underbrace{\overline{\mathbf{v}_{H,j}} \nabla \psi_j(x, y)}_{\text{advection}} + \underbrace{S_{e,j} + S_{w,j}}_{\substack{\text{sources \& sinks} \\ \text{(emission, nucleation,} \\ \text{washout)}}} + \underbrace{f_{diff} \cdot \Delta \psi_j(x, y)}_{\text{artificial diffusion}} + \underbrace{\frac{\psi_{clim,j}(x, y) - \psi_j(x, y)}{\tau_{clim,j}}}_{\text{relaxation to climatology}}$$

Horizontal transport of 2D-AOD: Using vertically averaged wind

Artificial diffusion: ‘Accounting’ for the effects of vertical wind shear

Parameterized emissions: based on Kok et al. 2014 (mineral dust) and Grythe et al. 2014 (sea salt)

Prescribed emissions: based on EDGAR (Crippa et al. 2016) for SO_2 , NO_x , NH_3 , BC, OC

Sulfate nucleation: simple parameterization if conditions are favorable for nucleation

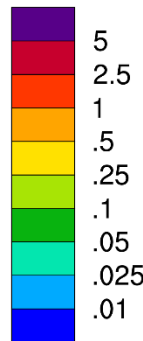
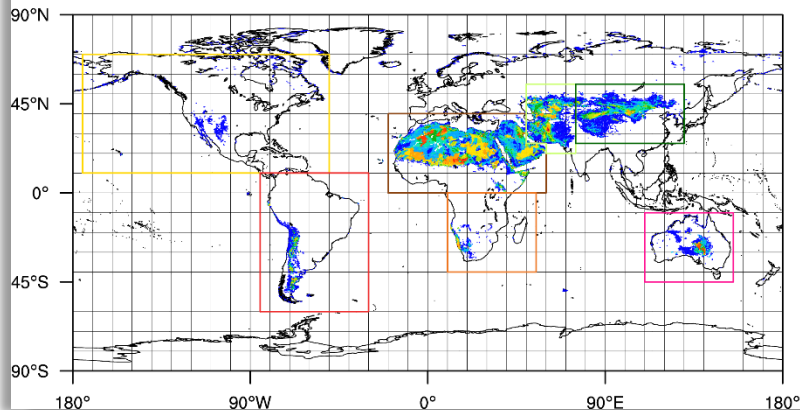
Wildfire climatology (10y): seasonal averages of wildfire emissions (SO_2 , BC, OC); quadratic regression

prog2Daero in a nutshell

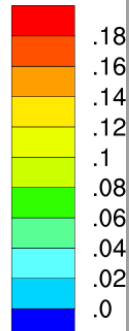
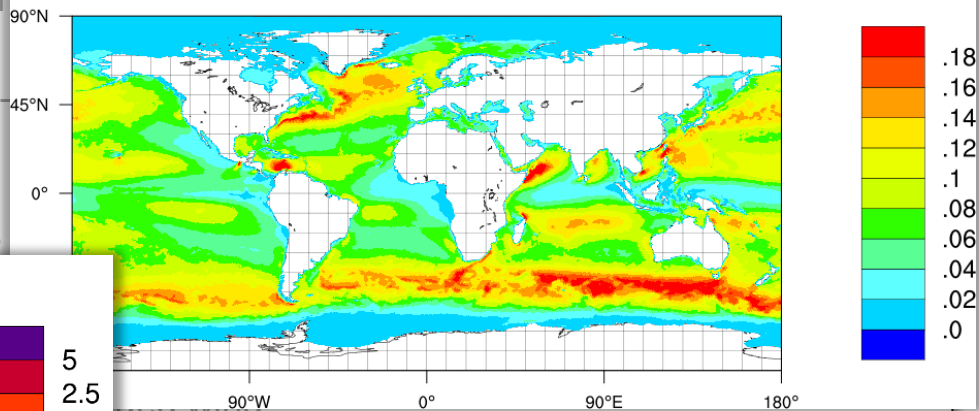
Prognostic equation for 2D-AOD $\psi_j(x, y)$ (r

$$\frac{\partial \psi_j(x, y)}{\partial t} = \underbrace{\overline{v_{H,j}} \nabla \psi_j(x, y)}_{\text{advection}} + \underbrace{S_{e,j} + S_{w,j}}_{\text{sources \& sinks}}$$

Accumulated Mineral Dust Emission Flux ($\text{kg m}^{-2} \text{yr}^{-1}$)



Accumulated Sea Salt Emission Flux ($\text{kg m}^{-2} \text{yr}^{-1}$)



l wind shear

mineral dust) and Grythe et al. 2014 (sea salt)

2016) for SO_2 , NO_x , NH_3 , BC, OC

s are favorable for nucleation

e emissions (SO_2 , BC, OC); quadratic regression

prog2Daero in a nutshell

Prognostic equation for 2D-AOD $\psi_j(x, y)$ (t

$$\frac{\partial \psi_j(x, y)}{\partial t} = \underbrace{\overline{v_{H,j}} \nabla \psi_j(x, y)}_{\text{advection}} + \underbrace{S_{e,j} + S_{w,j}}_{\text{sources \& sinks (emission, nucleation, washout)}}$$

Horizontal transport of 2D-AOD: Using vertically

Artificial diffusion: 'Accounting' for the effects of

Parameterized emissions: based

Prescribed emissions: based on Crippa

Sulfate nucleation: simple parameterization if con

Wildfire climatology (10y): seasonal averages of

See also Muskatel et al., 2026

Consortium



for

Small-Scale Modelling

Technical Report No. 53

*The COSMO Priority Project CAIIR:
Clouds and Aerosols Improvements
in ICON Radiation Scheme
Final Report*

August 2026

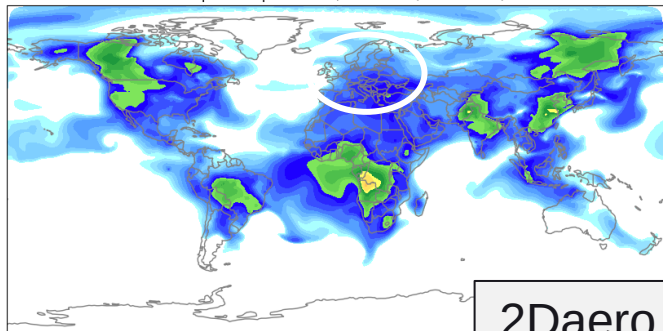
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_53

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



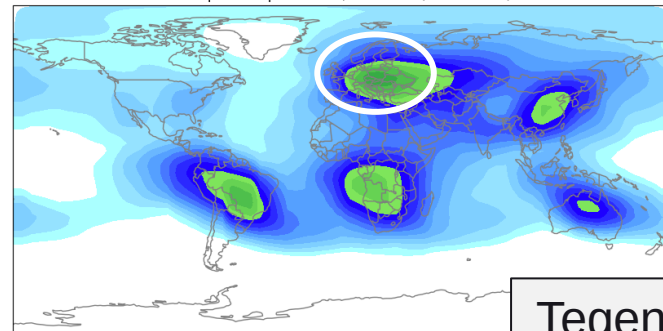
prog2Daero: Black Carbon

2023071500 Black Carbon Optical Depth 550nm, Min: 0.000, Max: 0.102, Median: 0.001



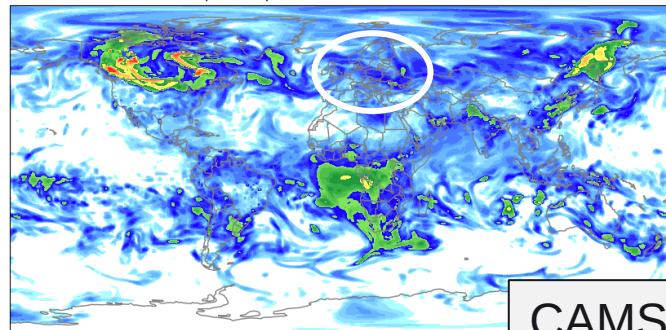
2Daero

2023071500 Black Carbon Optical Depth 550nm, Min: 0.000, Max: 0.039, Median: 0.002



Tegen

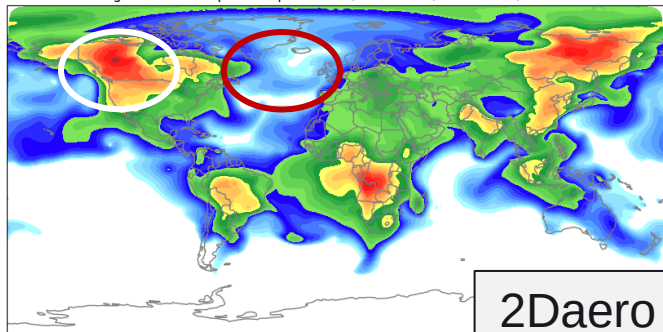
2023071500 Black Carbon Optical Depth 550nm, Min: 0.000, Max: 0.582, Med: 0.002



CAMS

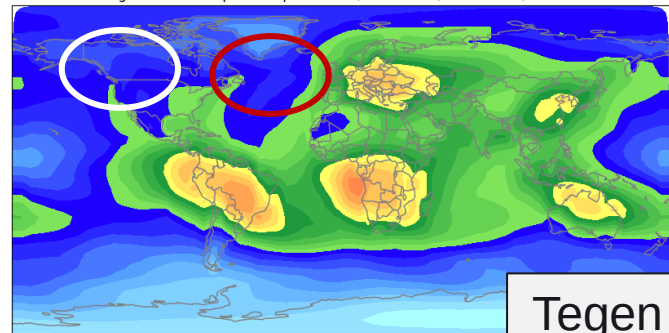
prog2Daero: Organic Carbon

2023071500 Organic Carbon Optical Depth 550nm, Min: 0.000, Max: 0.631, Median: 0.004



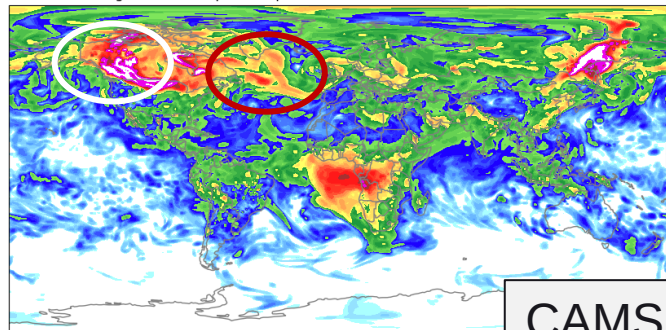
2Daero

2023071500 Organic Carbon Optical Depth 550nm, Min: 0.001, Max: 0.213, Median: 0.015



Tegen

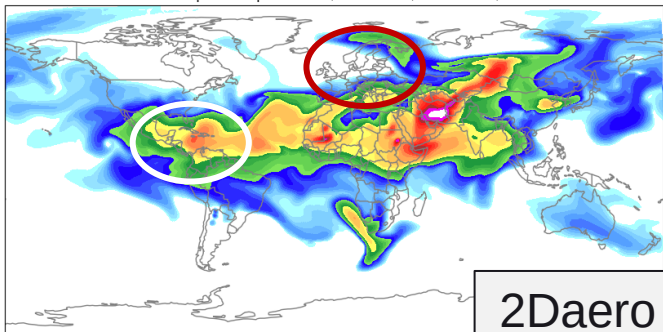
2023071500 Organic Matter Optical Depth 550nm, Min: 0.000, Max: 7.599, Med: 0.005



CAMS

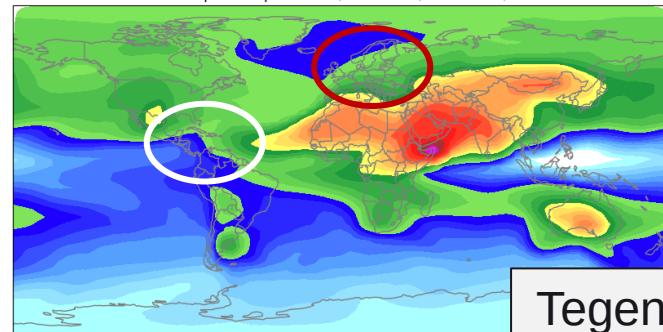
prog2Daero: Mineral Dust

2023071500 Mineral Dust Optical Depth 550nm, Min: 0.000, Max: 1.913, Median: 0.001



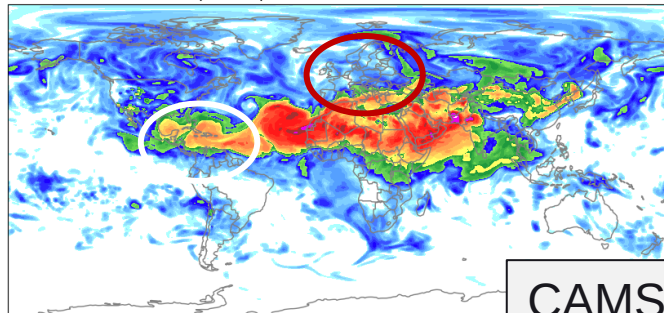
2Daero

2023071500 Mineral Dust Optical Depth 550nm, Min: 0.001, Max: 0.991, Median: 0.014



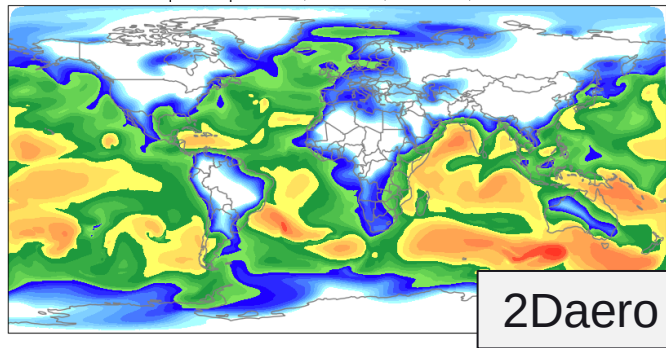
Tegen

2023071500 Mineral Dust Optical Depth 550nm, Min: 0.000, Max: 1.427, Med: 0.001

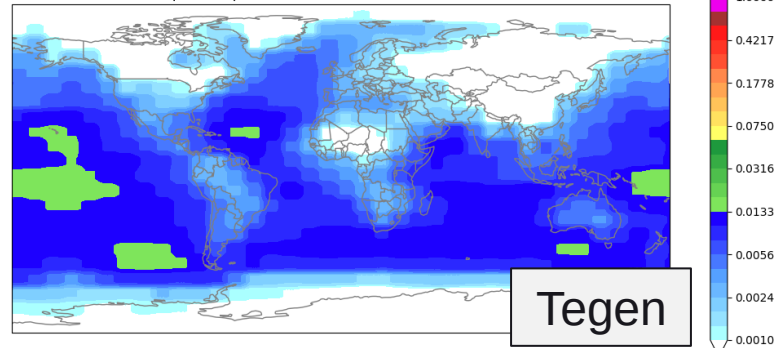


CAMS

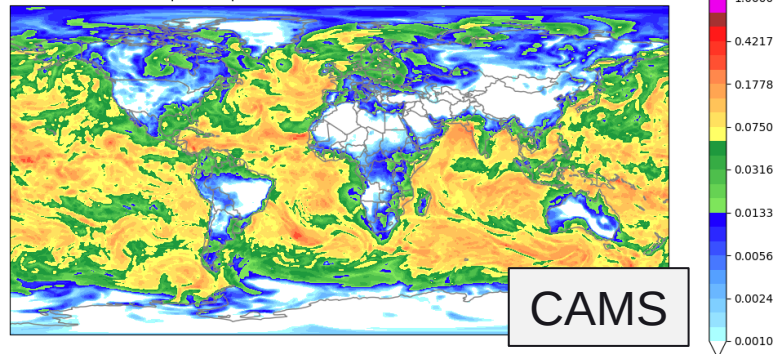
2023071500 Sea Salt Optical Depth 550nm, Min: 0.000, Max: 0.353, Median: 0.030



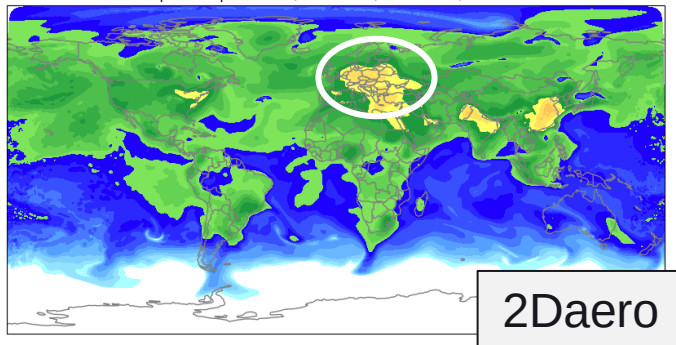
2023071500 Sea Salt Optical Depth 550nm, Min: 0.000, Max: 0.017, Median: 0.007



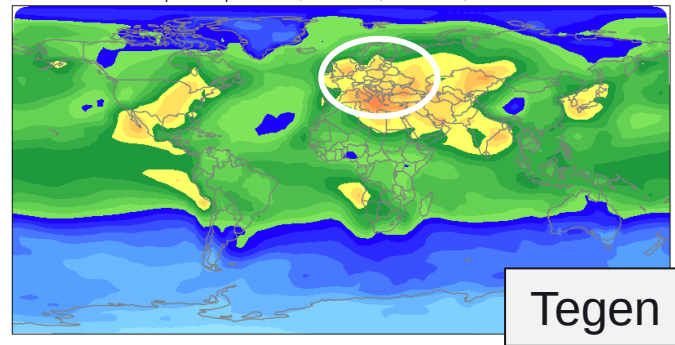
2023071500 Sea Salt Optical Depth 550nm, Min: 0.000, Max: 0.299, Med: 0.025



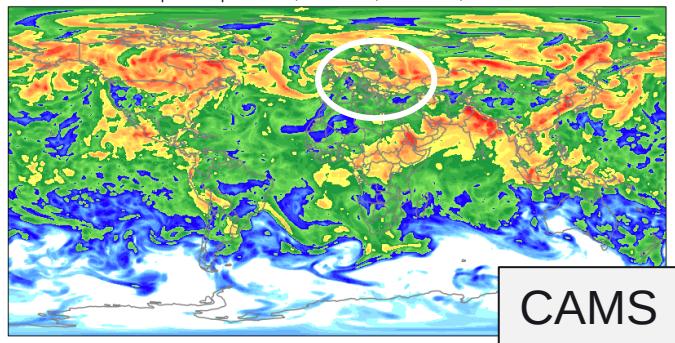
2023071500 Sulfate Optical Depth 550nm, Min: 0.000, Max: 0.100, Median: 0.012



2023071500 Sulfate Optical Depth 550nm, Min: 0.002, Max: 0.216, Median: 0.023

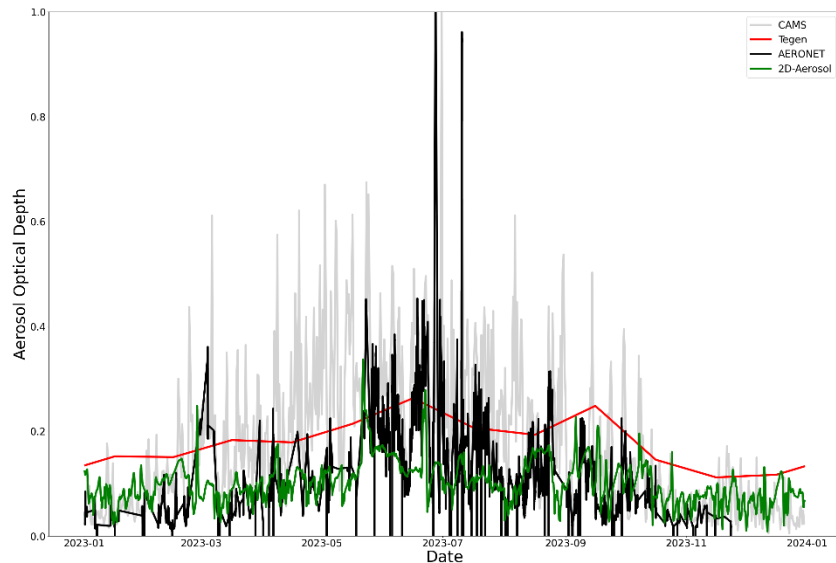


2023071500 Sulfate Optical Depth 550nm, Min: 0.000, Max: 0.827, Med: 0.020



prog2Daero: Comparison to AERONET

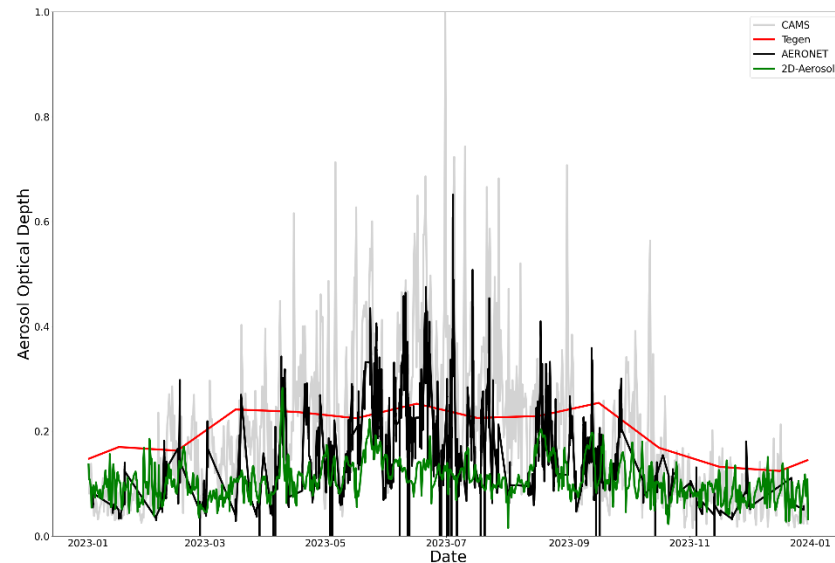
HohenpeissenbergDWD, 47.801900°N, 11.011900°E



AERONET

CAMS

MetObs_Lindenberg, 52.209275°N, 14.120870°E

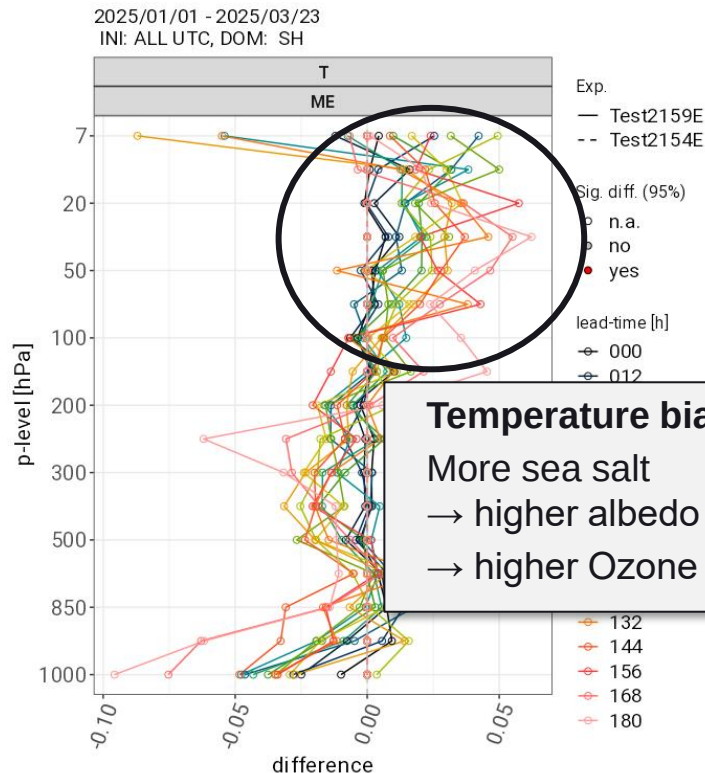


2D-Aerosol

Tegen

Setup:

- For now, 'everything except mineral dust' i.e., sea salt, sulfate, soot, and organic aerosols
- No explicit(!) change in the aerosol-cloud coupling
- Parameterization for moisture swelling of hygroscopic aerosols based on the RH dependence used in visibility diagnostics
- Winter period: 01 Jan – 15 March 2025 (+4 days spinup)
- Summer period: 01 May – 15 July 2025 (+4 days spinup)

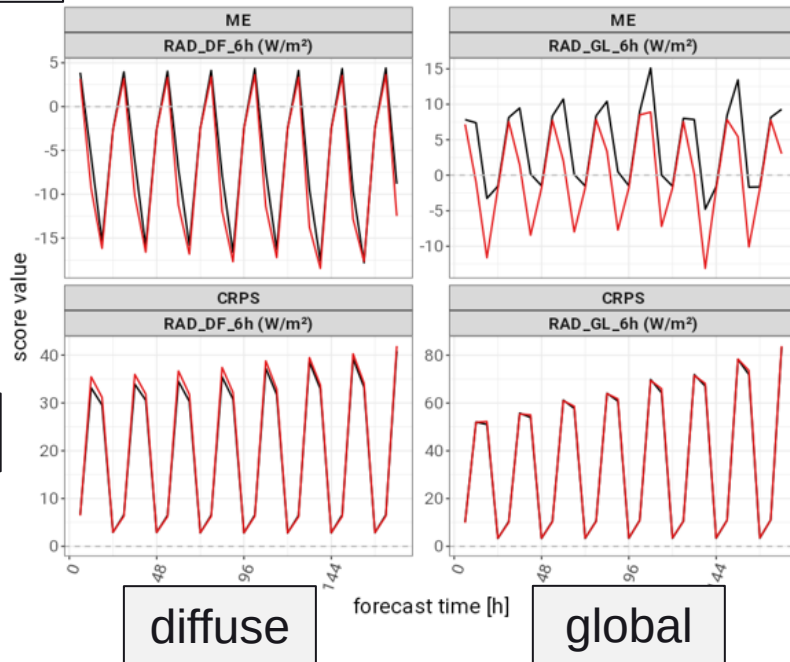


prog2Daero: Radiation Scores Germany (EPS)

Summer

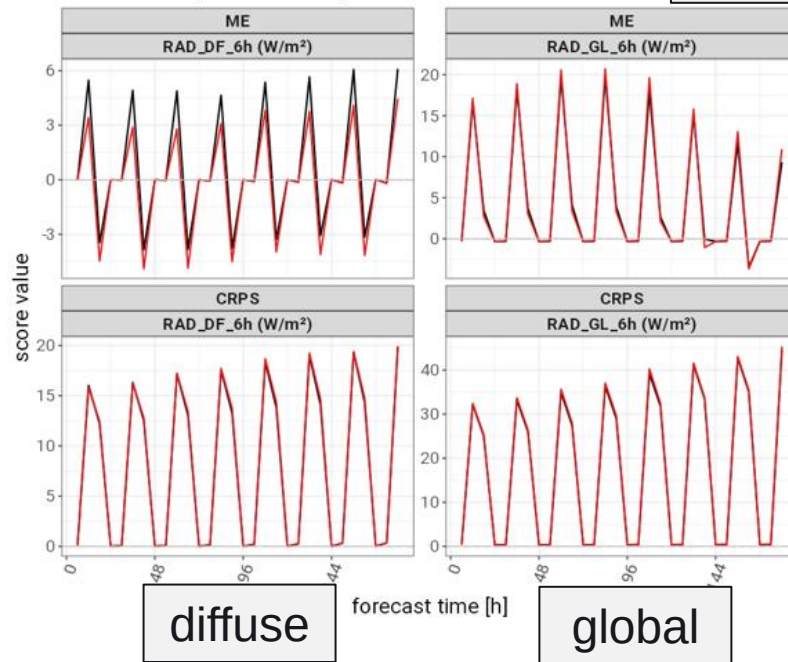
2025/05/01 00UTC - 2025/07/23 00UTC
INI: 00 UTC, DOM: CDE, STAT: ALL

ME



2025/01/01 00UTC - 2025/03/23 00UTC
INI: 00 UTC, DOM: CDE, STAT: ALL

Winter



Seasonal Hotspots

Large wildfire locations are remarkably constant in the last decade

Climatological dataset

10y seasonal averages 2015-2024

Wildfire emissions of SO_2 , BC, OC

Available in Extpar/Zonda

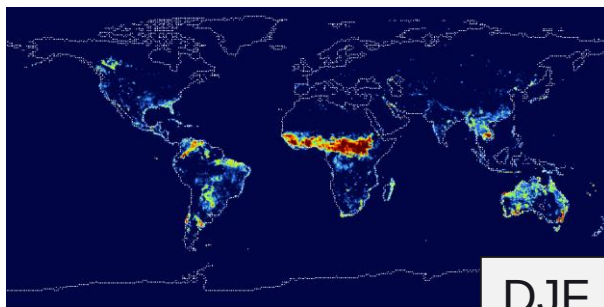
Inclusion in ICON

Quadratic regression

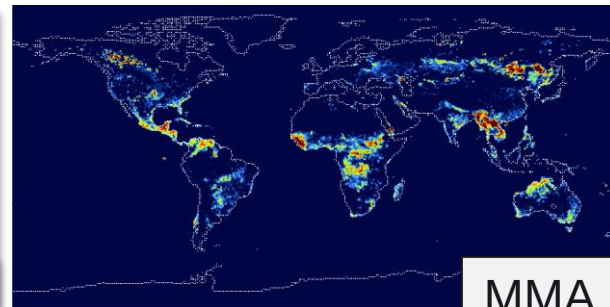
AOD source with empirical factor

One the right

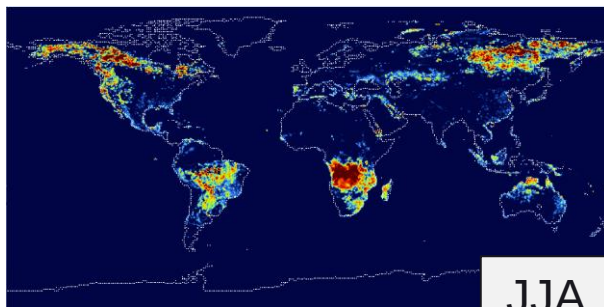
Seasonal cycle (qualitative)



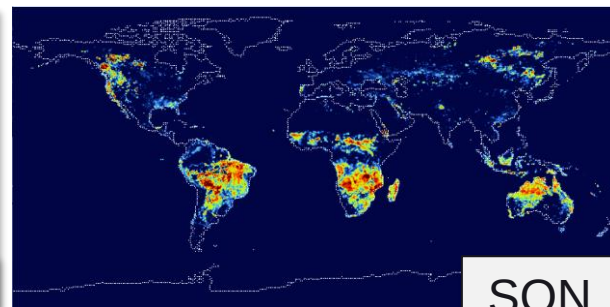
DJF



MMA



JJA



SON

Seasonal Hotspots

Large wildfire locations are remarkably constant in the last decade

Climatological dataset

10y seasonal averages 2015-2024

Wildfire emissions of SO_2 , BC, OC

Available in Extpar/Zonda

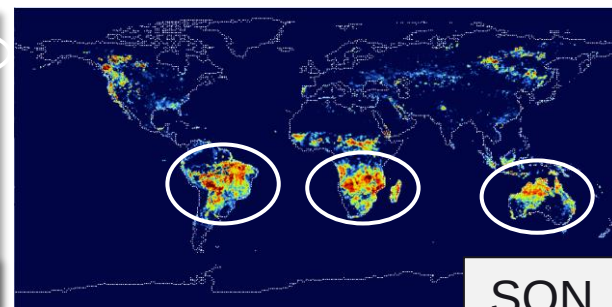
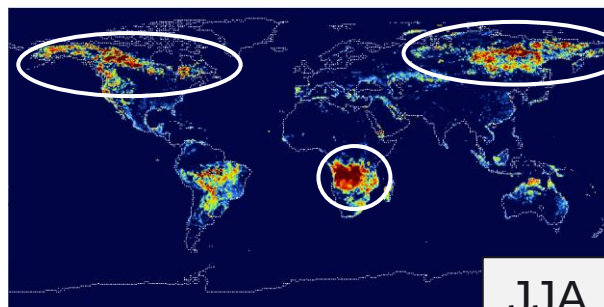
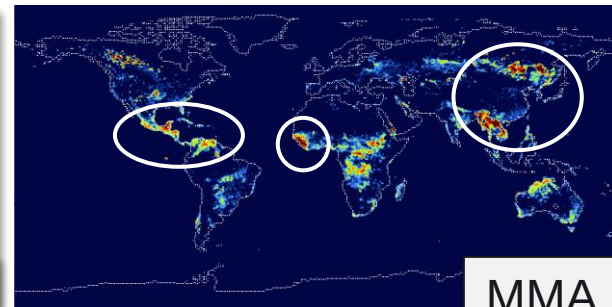
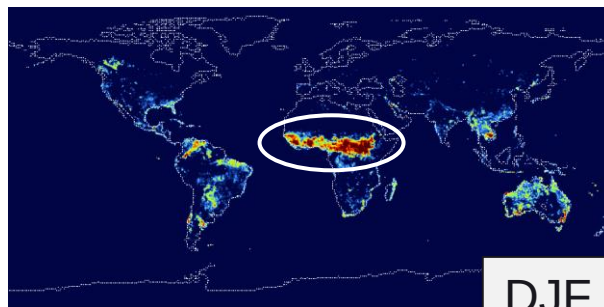
Inclusion in ICON

Quadratic regression

AOD source with empirical factor

One the right

Seasonal cycle (qualitative)

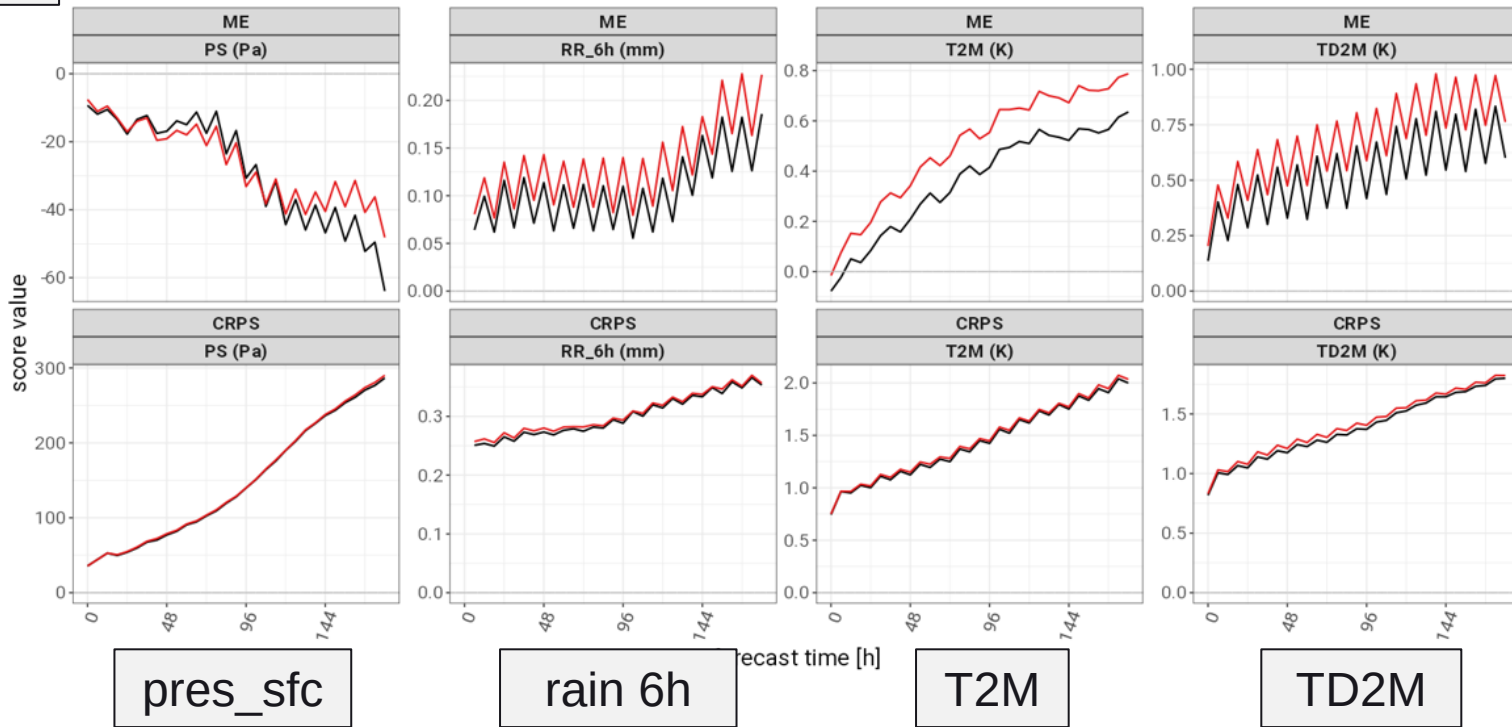


prog2Daero: Effect of Wildfires

Summer

2025/05/01 00UTC - 2025/07/23 00UTC
INI: ALL UTC, DOM: N Northamerica, STAT: ALL

ME



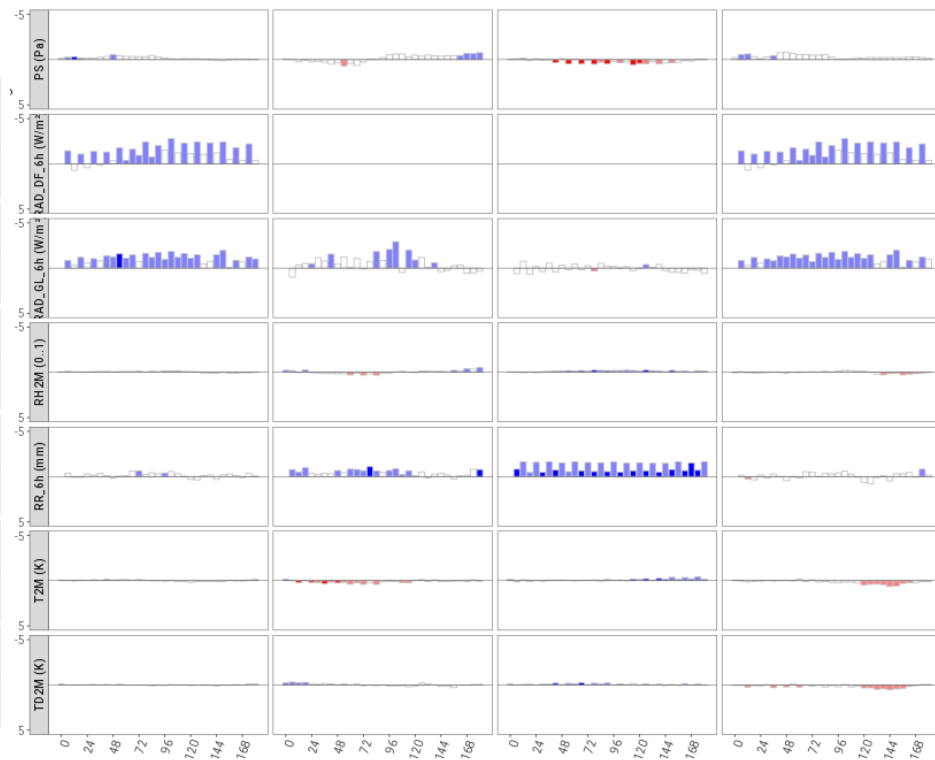
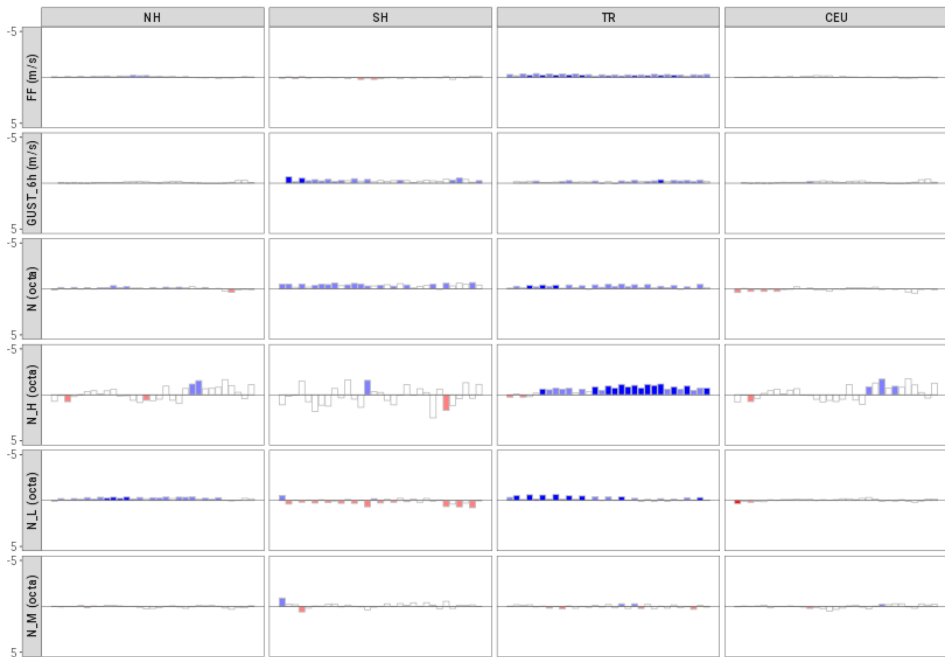
prog2Daero: Scorecard EPS Winter

Forecasts initialized from 2025/01/01 00UTC - 2025/03/23 00UTC

Change in CRPSF [%],

INI: 00, 12UTC, SIGTEST: TRUE, STATIONS: ALL

Significance  0.00 0.25 0.50 0.75 1.00 Test2154EPS-E lower Test2159EPS-E lower



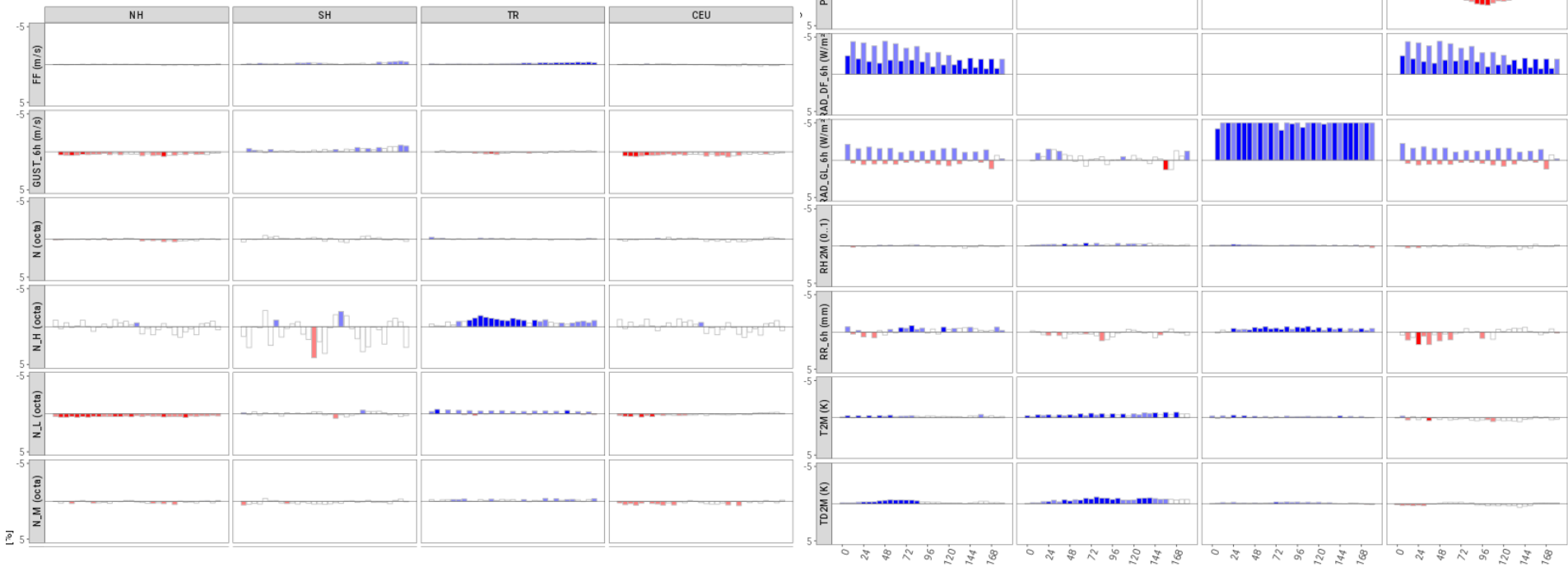
prog2Daero: Scorecard EPS Summer

Forecasts initialized from 2025/05/01 00UTC - 2025/07/23 00UTC

Change in CRPSF [%]

INI: 00, 12UTC, SIGTEST: TRUE, STATIONS: ALL

Significance  Test2153EPS-E lower  Test2160EPS-E lower 



Currently Operational:

Tegen climatological aerosol
5 species: BC, OC, SO₄, , sea salt
AOD@550nm; vertical: exp. decay

Known Deficiencies:

From the 1990s → outdated!

No interaction with weather patterns

Wildfires missing

Low-hanging fruit?

Sophisticated schemes are expensive

Can adding a minimum of complexity
improve the forecasts without adding a
major overhead (runtime/memory)?

Operational ICON-ART:

→ Replace dust AOD, SSA, g with
ICON-ART dust AOD, SSA, g

Keep other species from Tegen

prog2Daero complements ICON-ART!

Zonda now supports all necessary data!

*First application of 2D-Aerosol with ICON-ART:
see following presentation by Jochen Förstner*



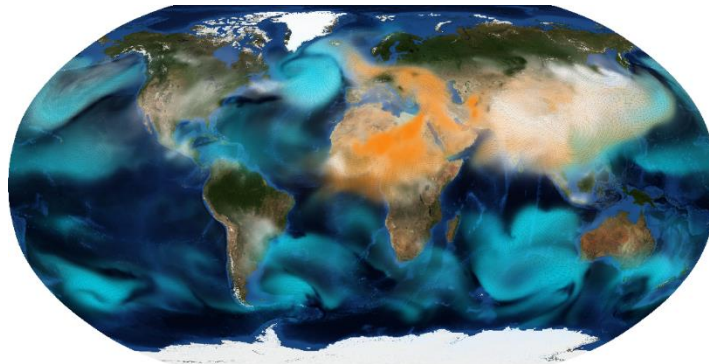
Summary:

- prog2Daero (w/o mineral dust) generally results in slight improvements in the bias of the radiative parameters (global + diffuse)
- Significant improvement only in the EPS scores
- In some regions (tropical, boreal) accounting for wild fires results in slight improvements that are statistically significant in the EPS, even in the temperature verification
- Additional computational effort < 0.5%

Operational since 2 September 2026! 

Outlook:

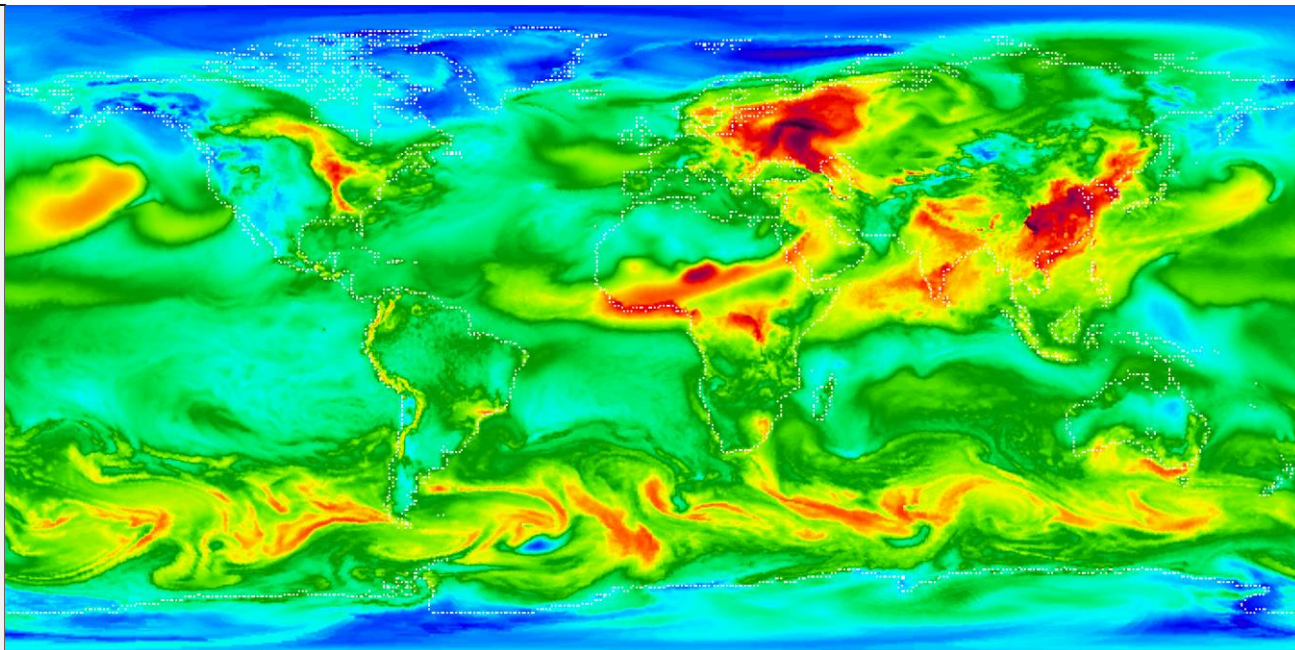
- Boundary conditions for limited-area mode
- AOD verification: AERONET / MODIS(?)
- Operationalization in ICON-ART Ensemble



Parameterization for moisture swelling of hygroscopic aerosols based on the RH dependence used in visibility diagnostics

Plan: Consistent AOD diagnostics incl. ICON-ART dust

Consistent to what the radiation gets!



Questions?



Daniel Rieger
Numerical Models Division
daniel.rieger@dwd.de

