

Kynning á spálausnum Belgings

Always good weather in Africa!!!

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Belgingur

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Hvað er Belgingur að gera?

- * Uppsetning á heildstæðri veðurspálausn fyrir UNECA
 - * UN Economic Commission for Africa
- * Auk þriggja ríkisveðurstofa
 - * Grænhöfðaeyjar
 - * Guinea-Bissau
 - * Sao-Tome og Principe
- * Innifelur vélbúnað, hugbúnað og þjálfun starfsmanna

Petta er fyrir sunnan okkur



Spálausnir Belgings



Spálausnir Belgings

- * Spákerfi uppsett og prófað á vélbúnaði
- * Framsetning á spám
 - * Mobile first vefur
 - * Hugsmiðjan hannar og vefar
- * Sveigjanleg eftirvinnsla
- * Gæðaeftirlitskerfi fyrir
 - * Spár
 - * Mælingar
- * Þjálfun starfsmanna
- * Möguleg þátttaka í frekari rannsóknarverkefnum

About ISOR (aka Iceland Geosurvey)

- * Established in 2003 when the GeoScience Division of the National Energy Authority of Iceland was spun off as a separate entity
- * A self-financing, state-owned, non-profit institution
- * More than six decades of continuous experience in the field of geothermal and hydropower research and development
- * Provides over half of the teaching staff of the UNU Geothermal Training Programme, operated since 1979

About Belgingur

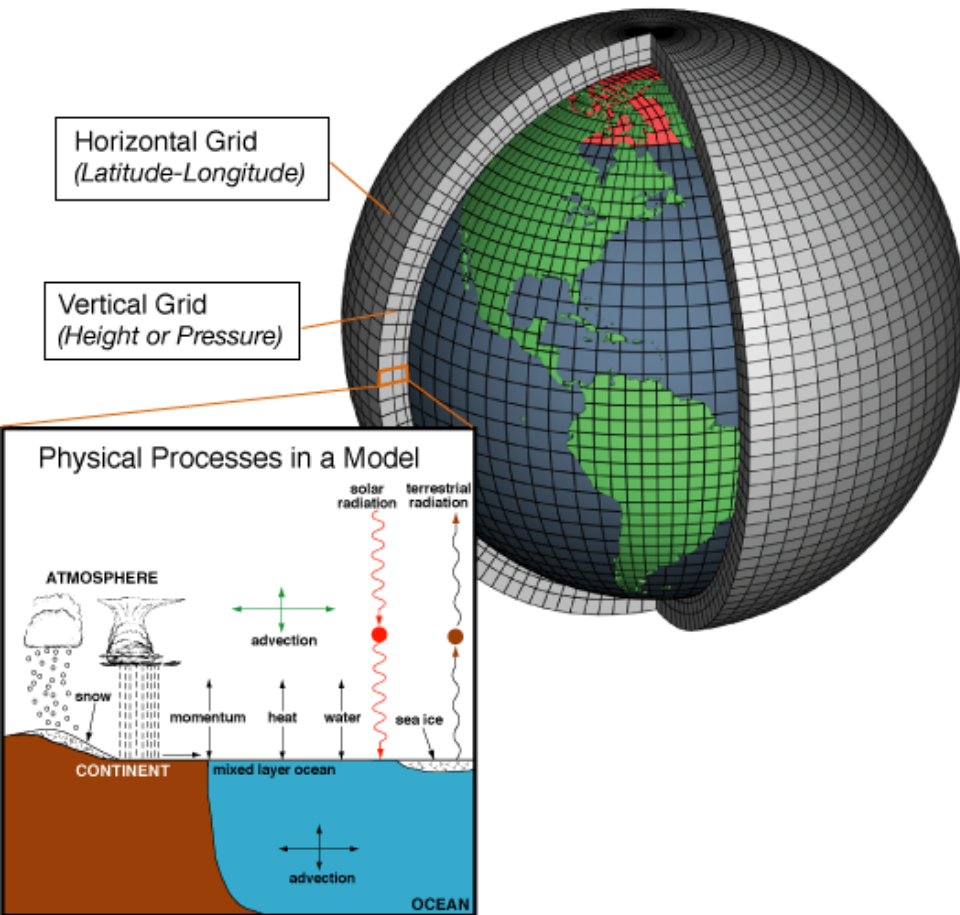
- * Founded in 2001 – www.belgingur.eu
- * Mixed private and governmental ownership
 - * 90% private
 - * 10% owned by ISOR (aka Iceland Geosurvey)
- * Strong tradition in atmospheric research
 - * Atmospheric flow in complex terrain
 - * Dynamical downscaling of global climate data
- * Operational forecasts since 2004
 - * www.belgingur.is
- * On-Demand forecasts since 2012
 - * SARWeather – www.sarweather.com

Our network

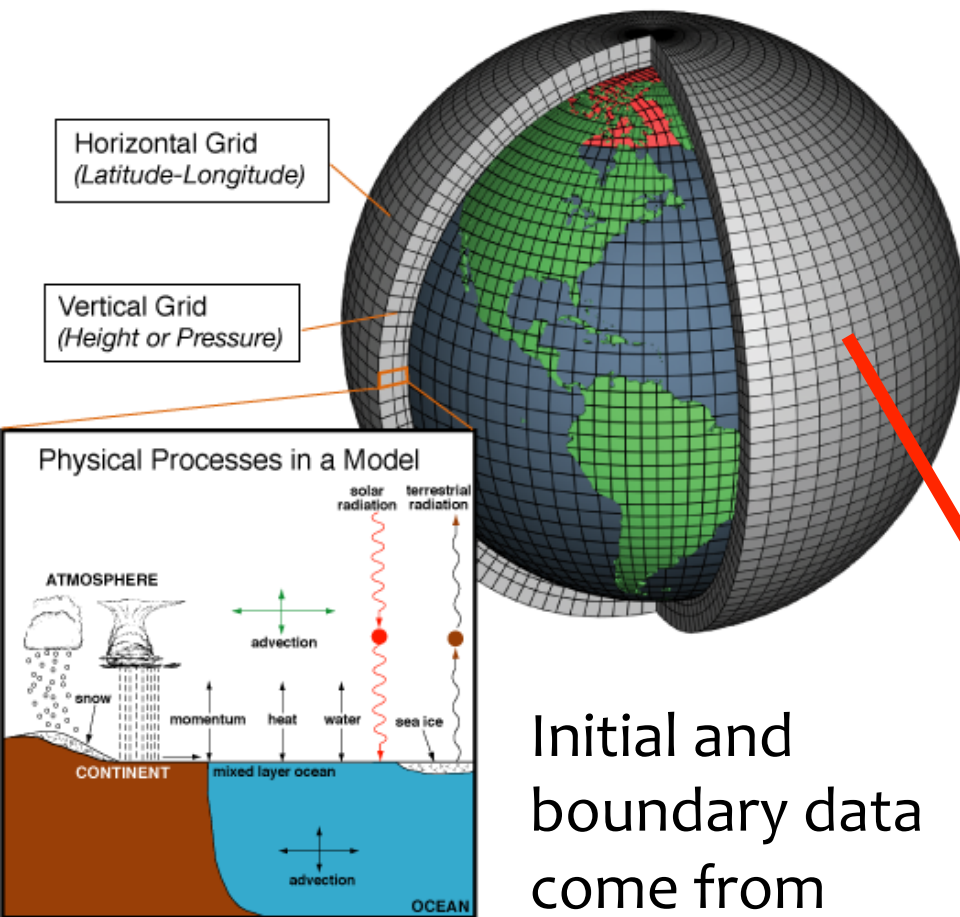
- * Long time collaborators with
 - * NOAA/ESRL in Boulder, USA
 - * ISOR, Iceland
 - * The Icelandic Meteorological Office
 - * University of Bergen, Norway
 - * University of Iceland and Reykjavík University, Iceland
- * Service provider for
 - * GDACS – Global Disaster and Alerts Coordination System
 - * SARWeather On-Demand forecasts
 - * Landsvirkjun – The Icelandic Power Company
 - * Vegagerðin – The Icelandic Road Authorities
 - * The Icelandic Meteorological Office (2004-2012)
 - * Eneco Ltd., the Netherlands
 - * 365 Media, Iceland

Atmospheric models

Set of equations that describe the atmospheric flow and need to be integrated forward in time to produce a weather forecast

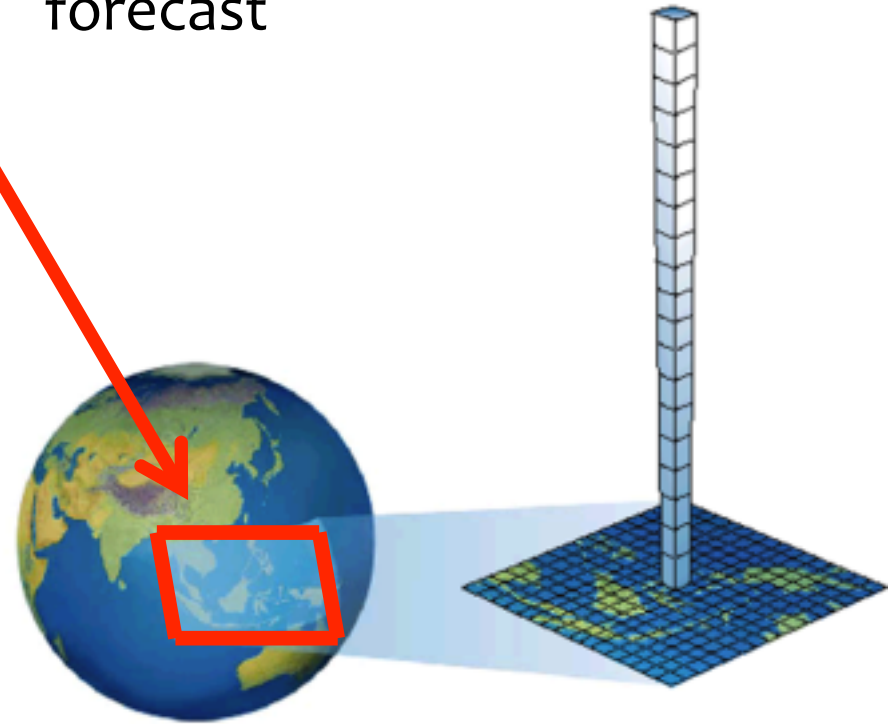


Atmospheric models



Set of equations that describe the atmospheric flow and need to be integrated forward in time to produce a weather forecast

Initial and boundary data come from global models

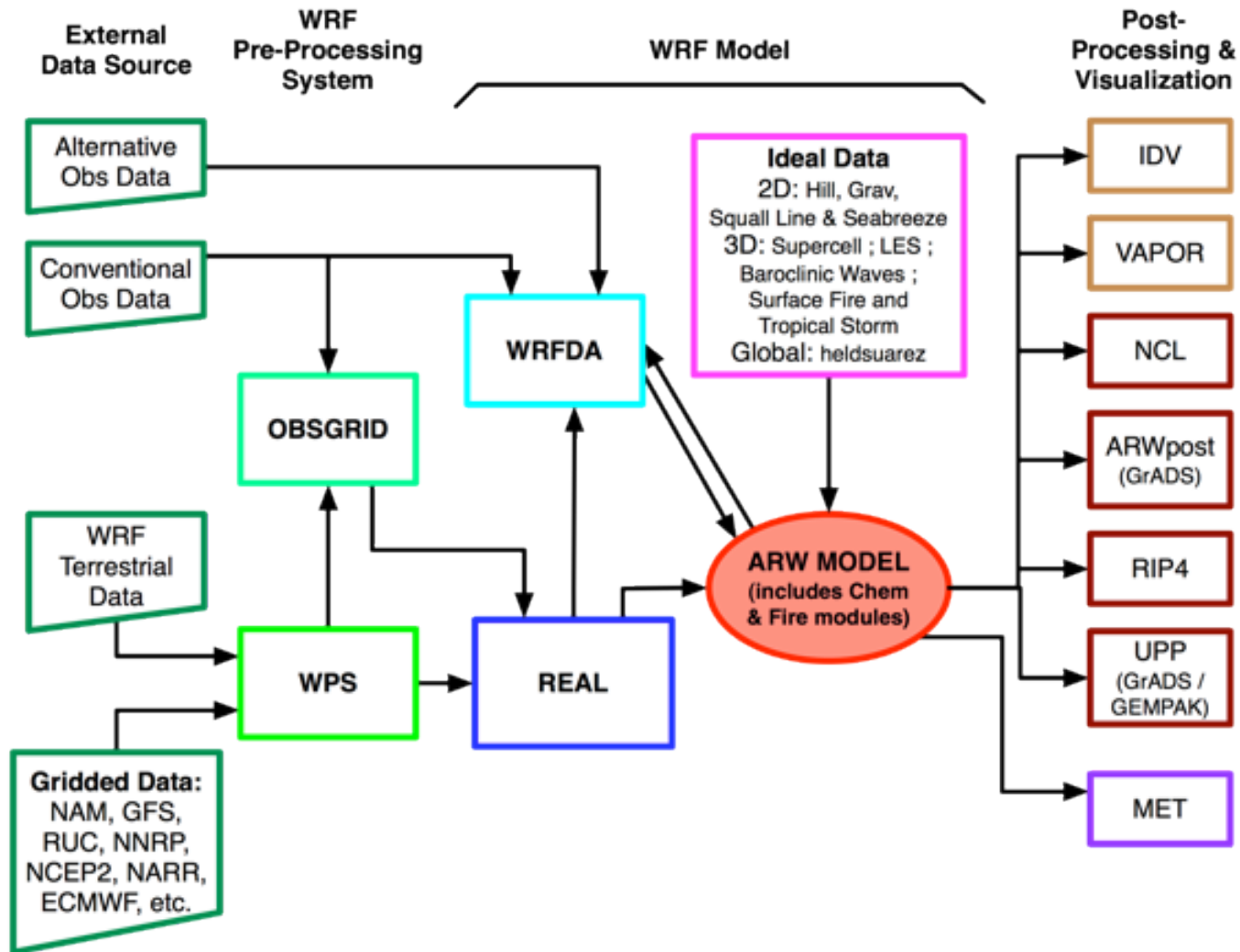


Regional

The WRF atmospheric model

- Open source model developed in collaboration of
 - NCAR, NOAA, AFWA, NRL, Univ. of Oklahoma & FAA
- Five development teams with sixteen workgroups
 - More than 160 official developer
 - Additional development by academic and governmental institutions in the US and abroad
 - Very large user community (>20.000), excellent support
- Non-hydrostatic
- Regional and global applications
- Wide range of scales for both real time and idealized applications
 - Optional data assimilation (3D-VAR, 4D-VAR, and FDDA)
 - Has been modified for volcanic applications
 - Includes a dust module (re-suspension of dust/ash)

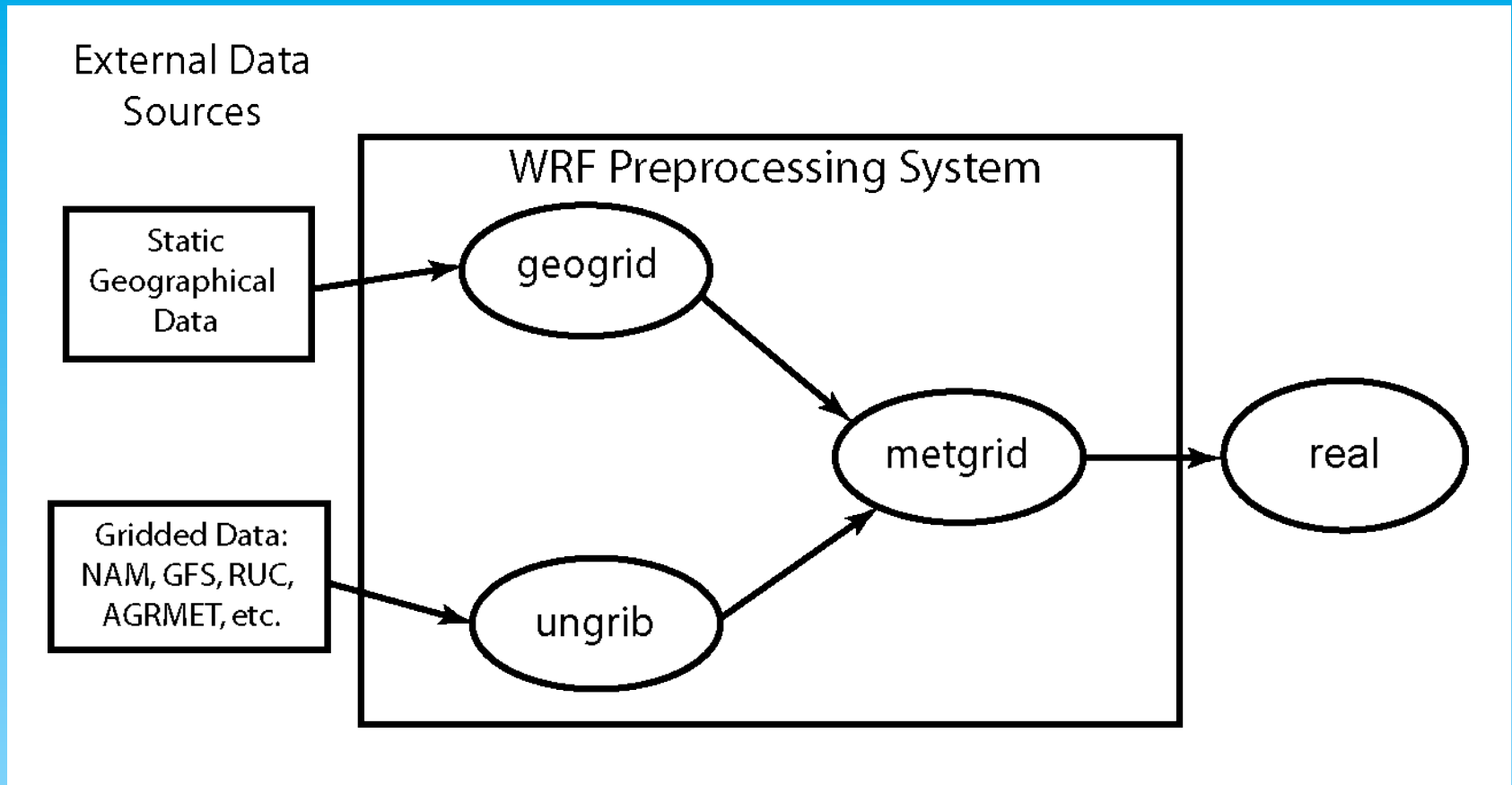
WRF modeling system flow chart



WPS - the WRF Pre-processing system

- The purpose of WPS is to prepare input to WRF for real-data simulations:
 1. Defines simulation coarse domain and ARW nested domains
 2. Computes latitude, longitude, map scale factors, and Coriolis parameters at every grid point
 3. Interpolates time-invariant terrestrial data to simulation grids (e.g., terrain height and soil type)
 4. Interpolates time-varying meteorological fields from another model onto simulation domains

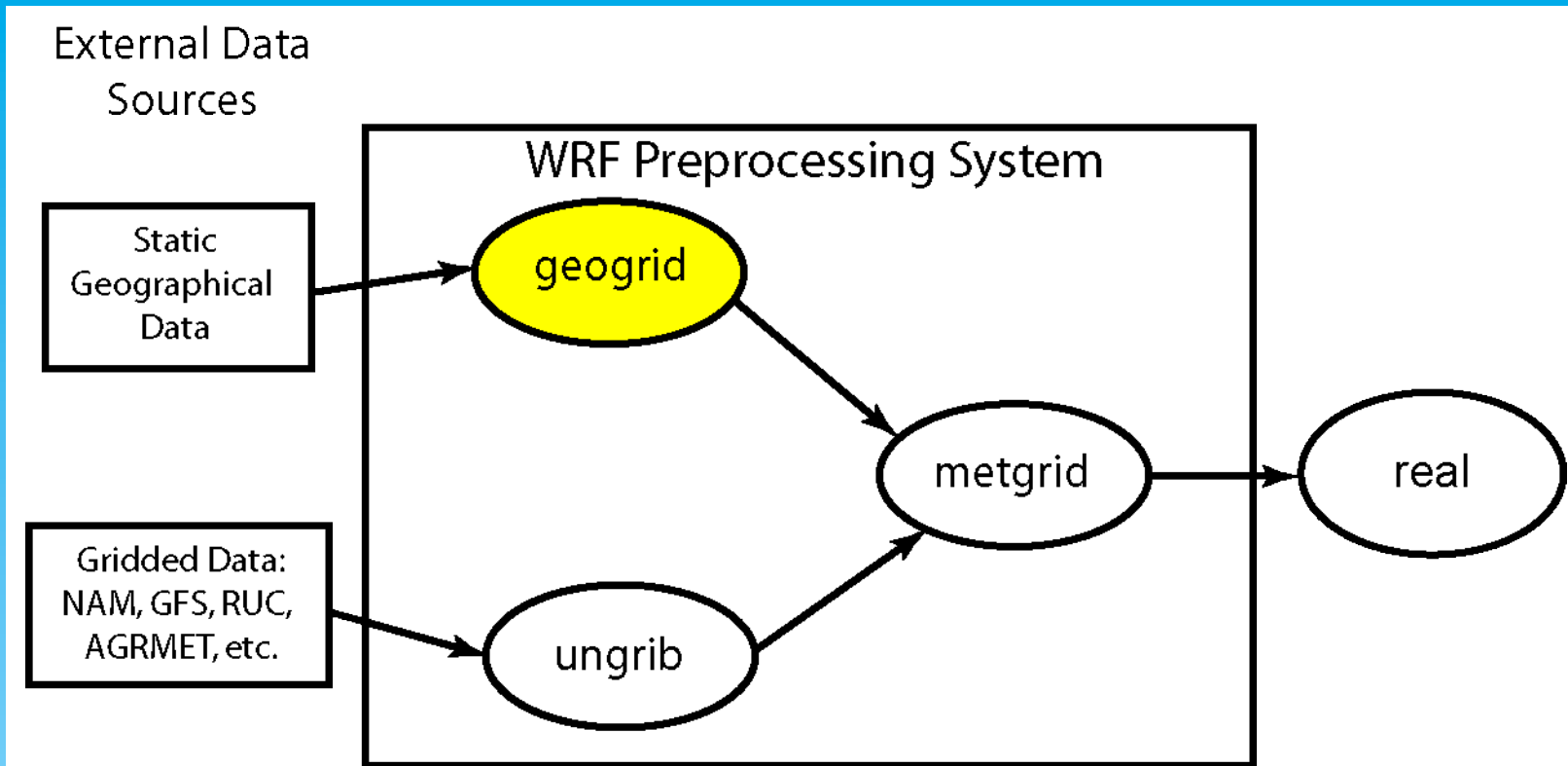
WPS flow chart



WPS - overview

- geogrid (think **ge**ographical)
 - Define size/location of model domains and interpolate static terrestrial fields to simulation grids
- ungrib (think **un**+**grib**)
 - Extract meteorological fields from GRIB files
- metgrid (think **me**teorological)
 - Horizontally interpolate meteorological fields (from ungrib) to simulation grids (defined by geogrid)

The geogrid program



geogrid: think geographical

The geogrid program

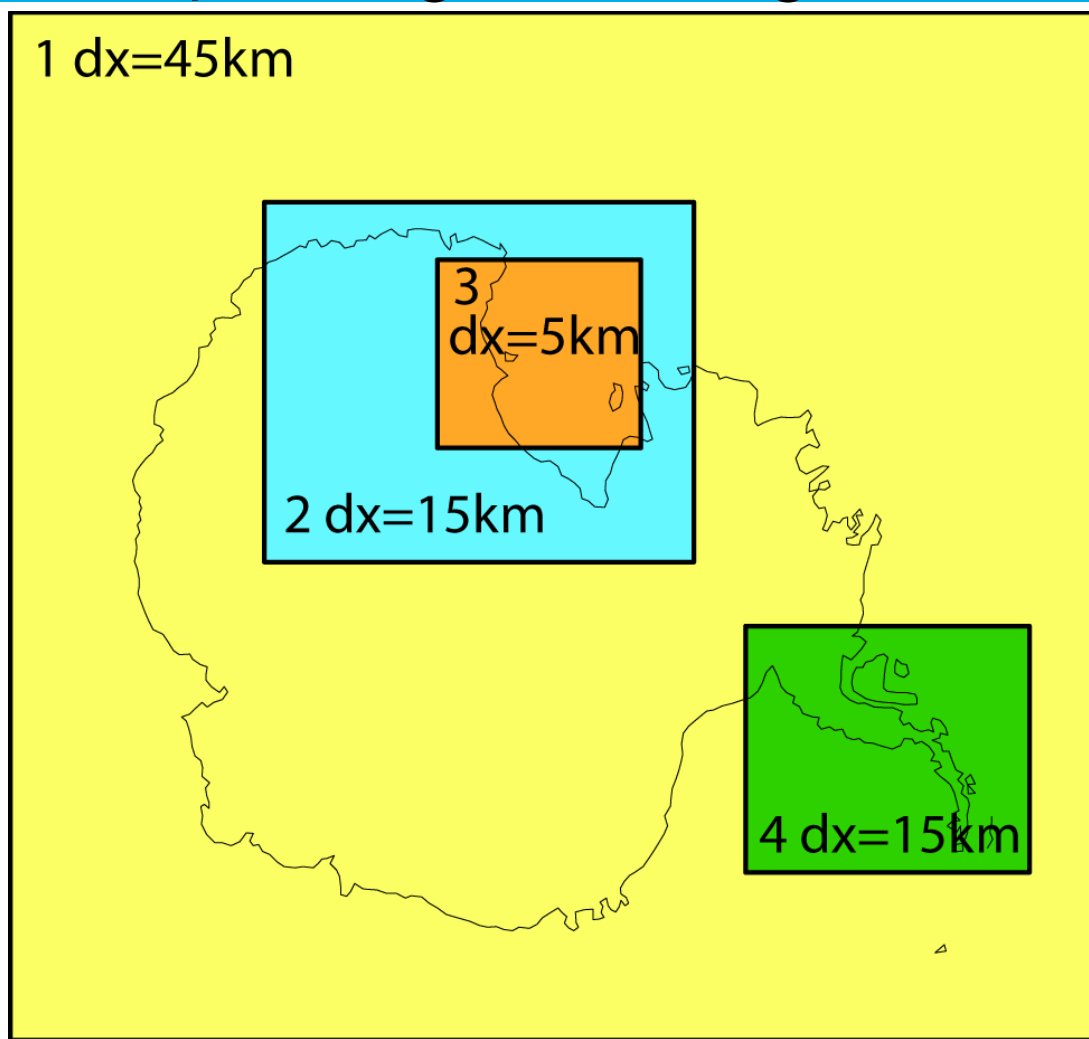
- For WRF model domains, geogrid defines:
 - Map projection (all domains must use the same projection)
 - Geographic location of domains - Dimensions of domains
- Geogrid provides values for static (time-invariant) fields at each model grid point
 - Compute latitude, longitude, map scale factor, and Coriolis parameters at each grid point
 - Horizontally interpolate static terrestrial data (e.g., topography height, land use category, soil type, vegetation fraction, monthly surface albedo)

Geogrid: Nesting basics

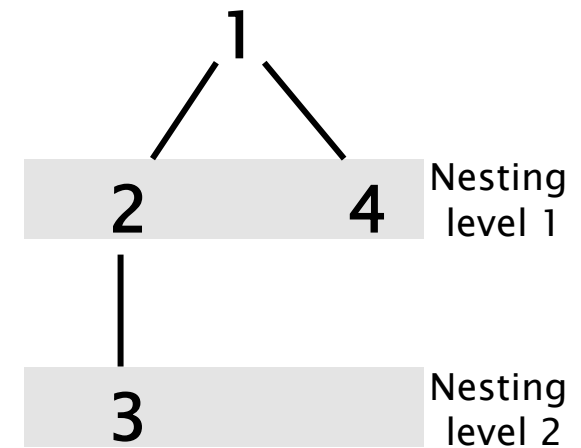
- A nested domain is a domain that is wholly contained within its parent domain and that receives information from its parent, and that may also feed information back to its parent
 - A nested domain has exactly one parent
 - A domain may have one or more children
- 2-way nests on the same nesting level must not overlap in coverage!

Geogrid: Nesting example

Example configuration using four domains



Each domain is assigned a domain ID #

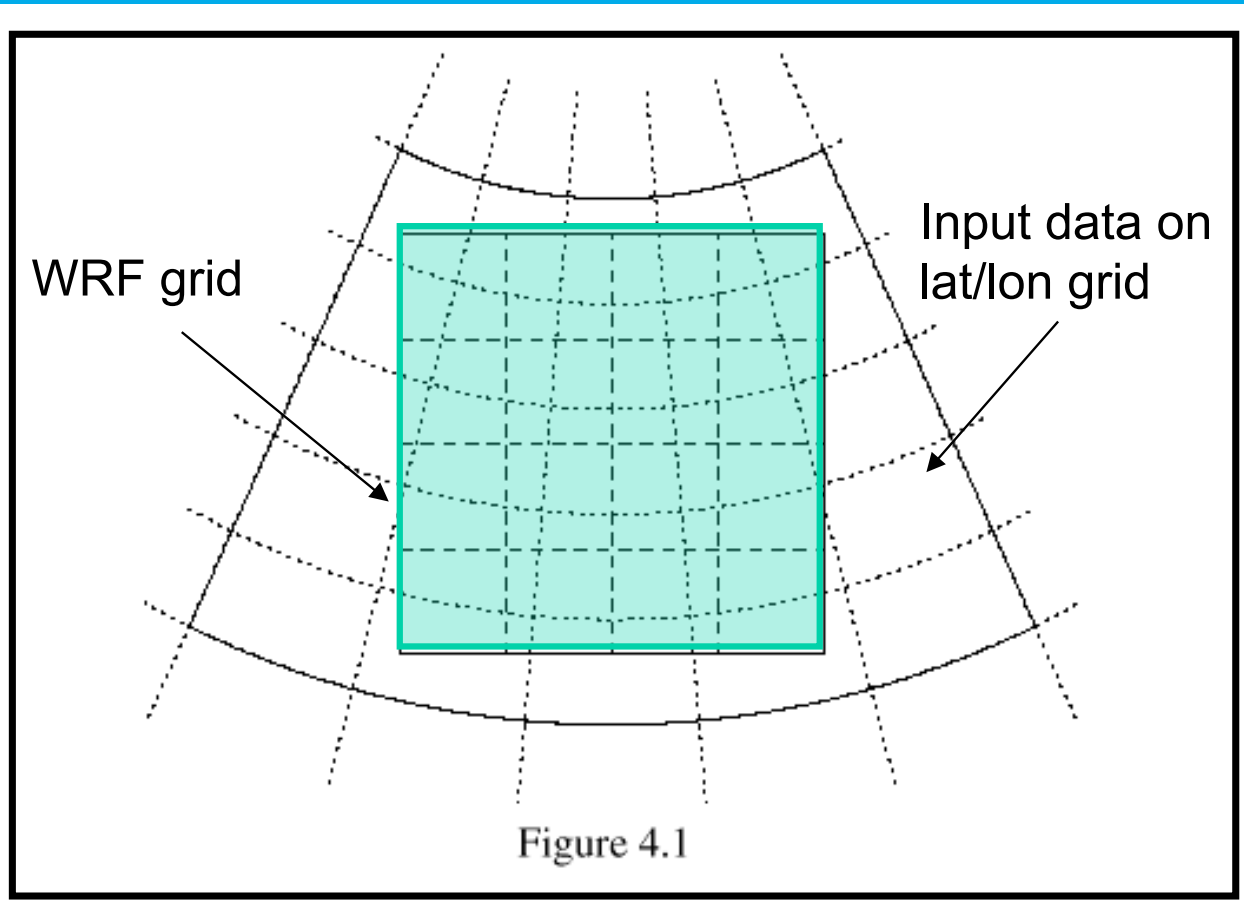


Nesting structure shown as a tree for the domains at left

Geogrid: Interpolating static fields

- Given definitions of all computational grids, geogrid interpolates terrestrial, time-invariant fields
 - Topography height
 - Land use categories
 - Soil type (top layer & bottom layer)
 - Annual mean soil temperature
 - Monthly vegetation fraction
 - Monthly surface albedo

Geogrid: Interpolating static fields

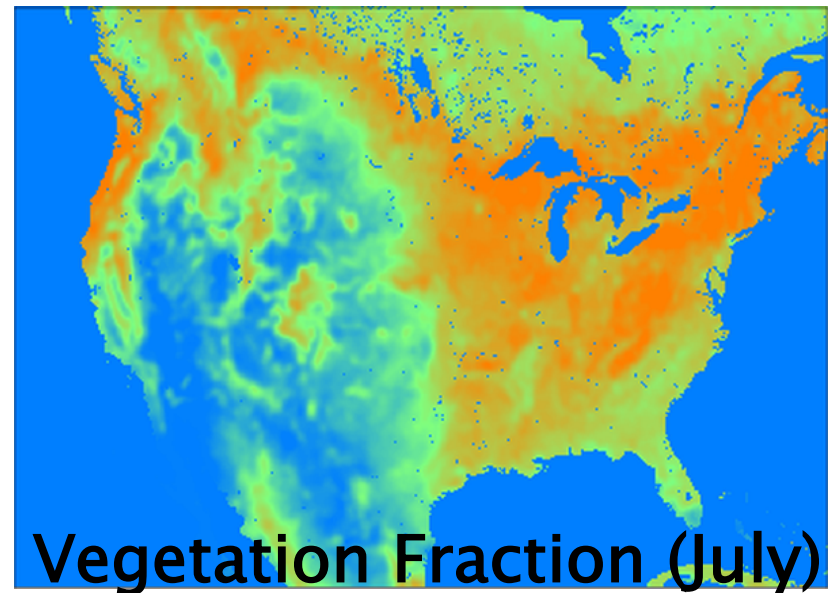
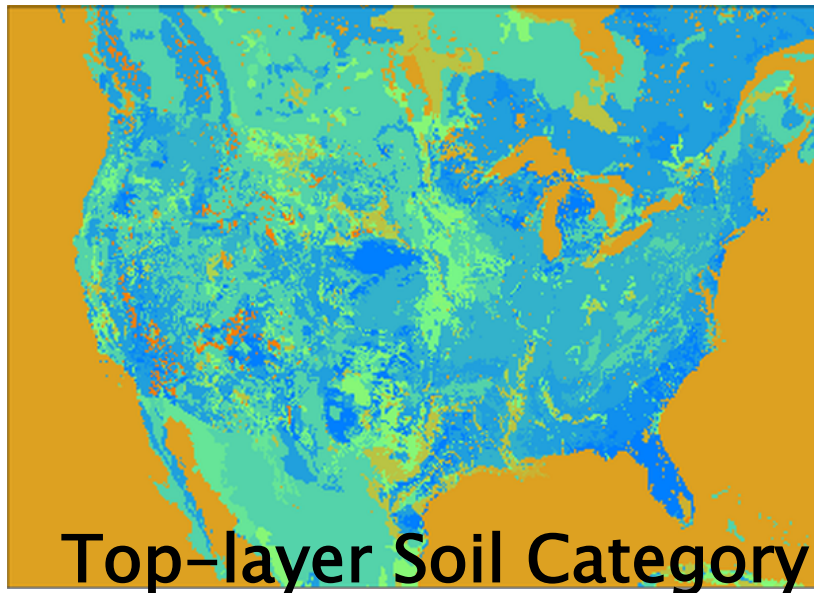
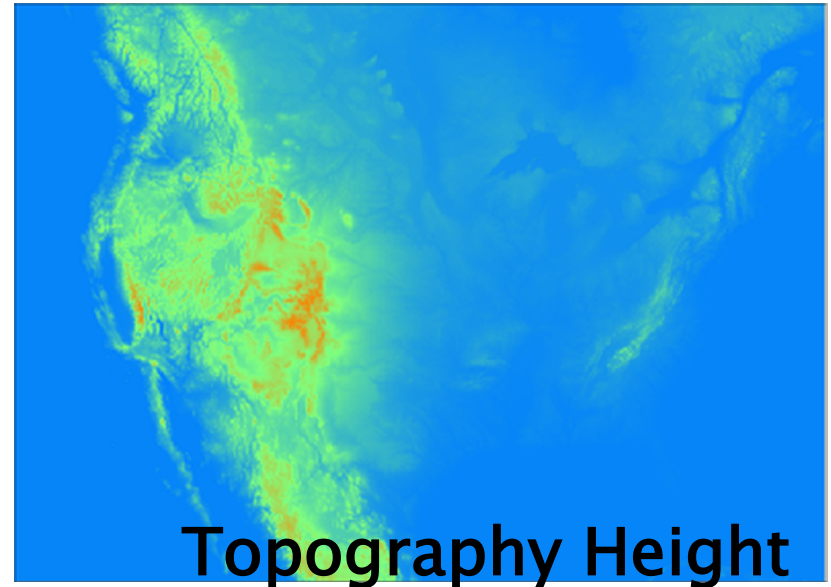


In general, source data are given on a different projection from the model grid

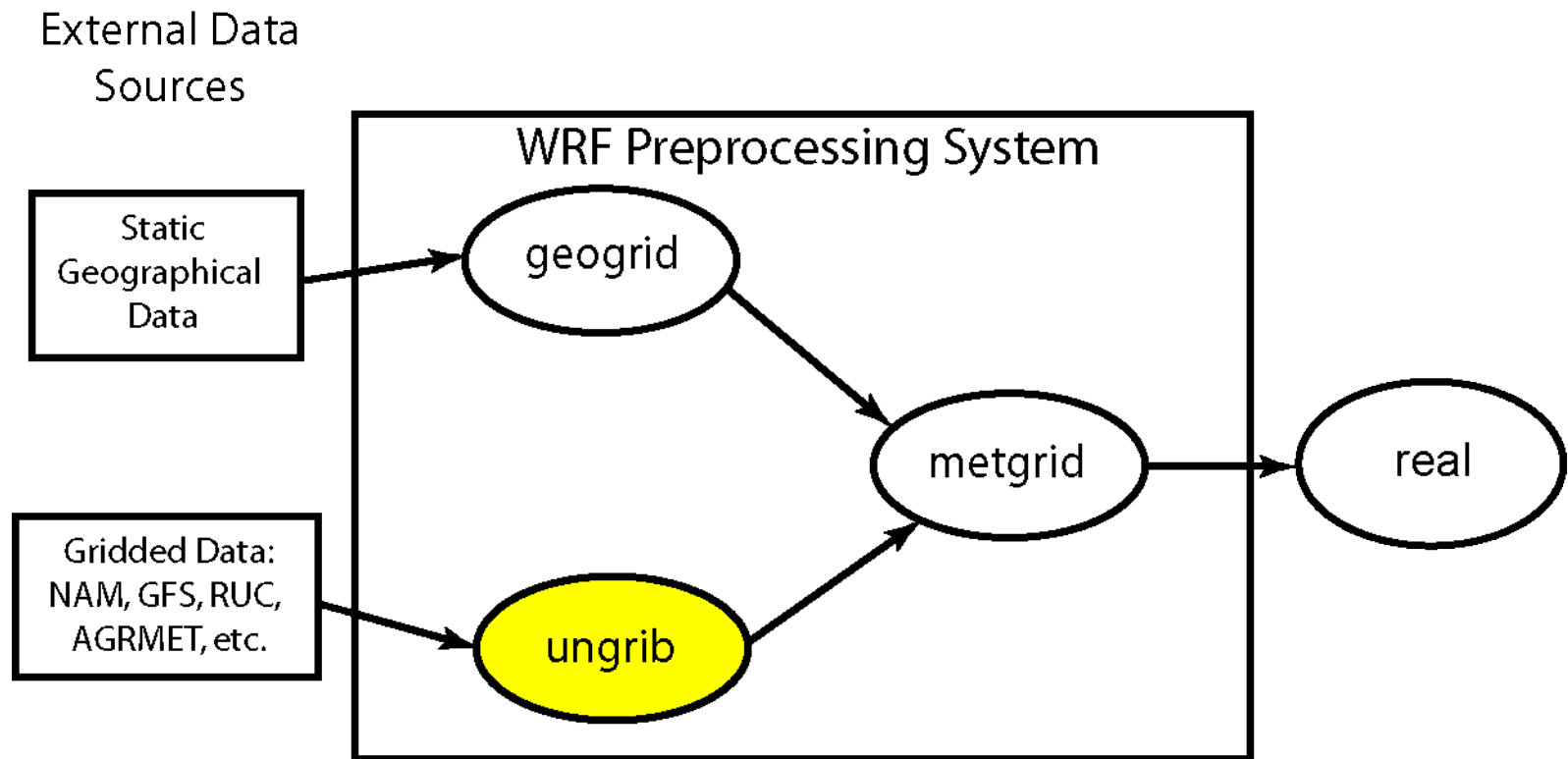
Geogrid: Output

- The parameters defining each domain, plus interpolated static fields, are written using the WRF I/O
 - One file per domain for ARW
- Filenames: `geo_em.d0n.nc`
 - (where n is the domain ID number)
- Example:
 - `geo_em.d01.nc`
 - `geo_em.d02.nc` (nest)
 - `geo_em.d03.nc` (nest)

Geogrid: Example output fields



The *ungrib* program



ungrib: think un+grib

The *ungrib* program

- Read GRIB Edition 1 and GRIB Edition 2 files
- Extract meteorological fields
- If necessary, derive required fields from related ones
 - E.g., compute RH from T, P, and Q
- Write requested fields to an intermediate file format

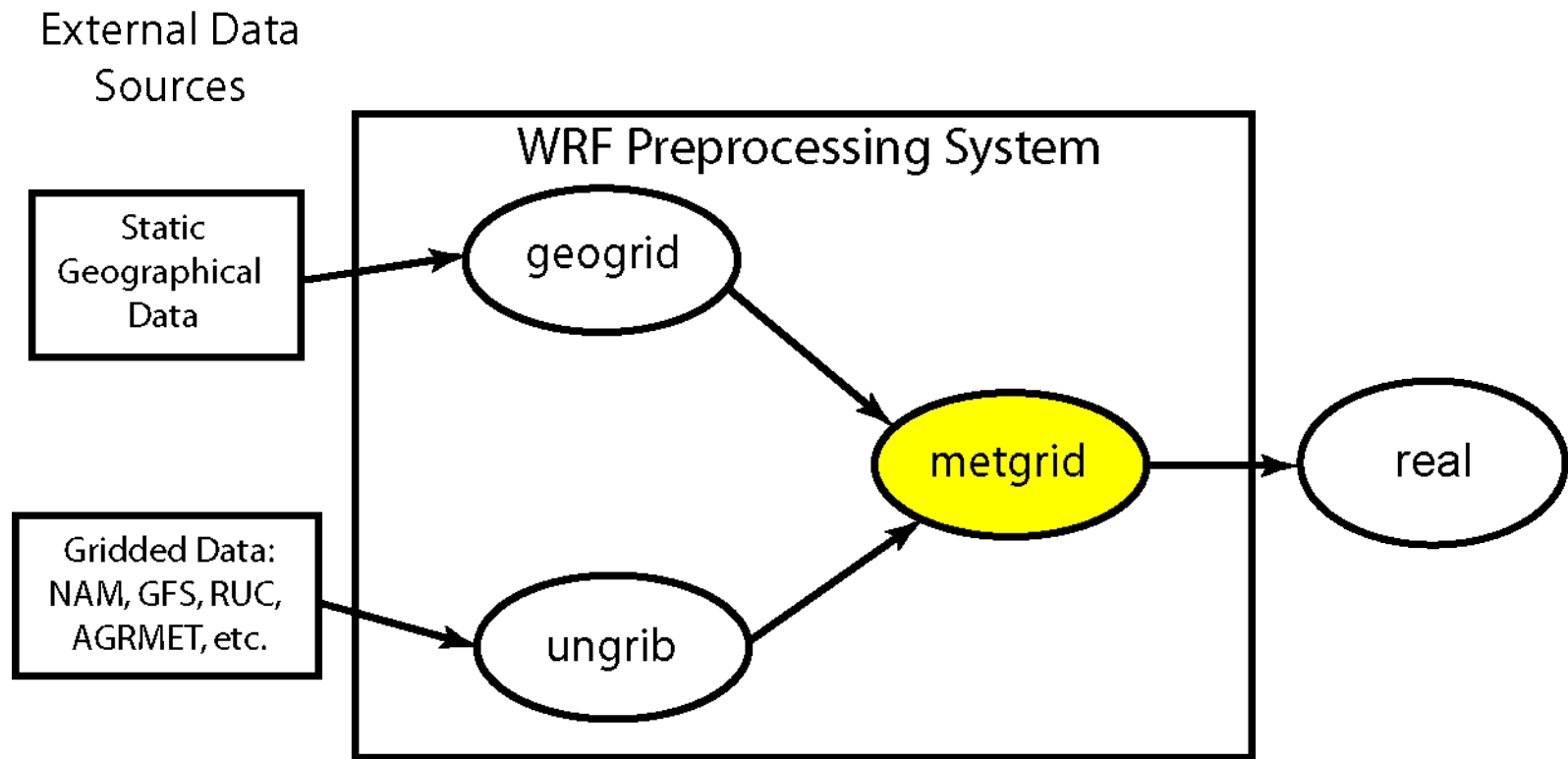
Uses Vtables (Vartibal tables) to identify which fields to extract

- Vtables are files that give the GRIB codes for fields to be extracted from GRIB input files
- One Vtable for each source of data
- Vtables are provided for: NAM 104, NAM 212, GFS, AGRMET, and others

Ungrib: Intermediate file format

- After extracting fields listed in Vtable, ungrib writes those fields to intermediate format
- For meteorological data sets not in GRIB format, the user may write to intermediate format directly
 - Allows WPS to ingest new data sources (basic programming required of user)
 - Simple intermediate file format is easily read/written using routines from WPS (`read_met_module.F` and `write_met_module.F`)
- Output files named FILE:YYYY-MM-DD_HH
 - YYYY is year of data in the file; MM is month; DD is day; HH is hour
 - All times are UTC

The *metgrid* program



metgrid: think meteorological

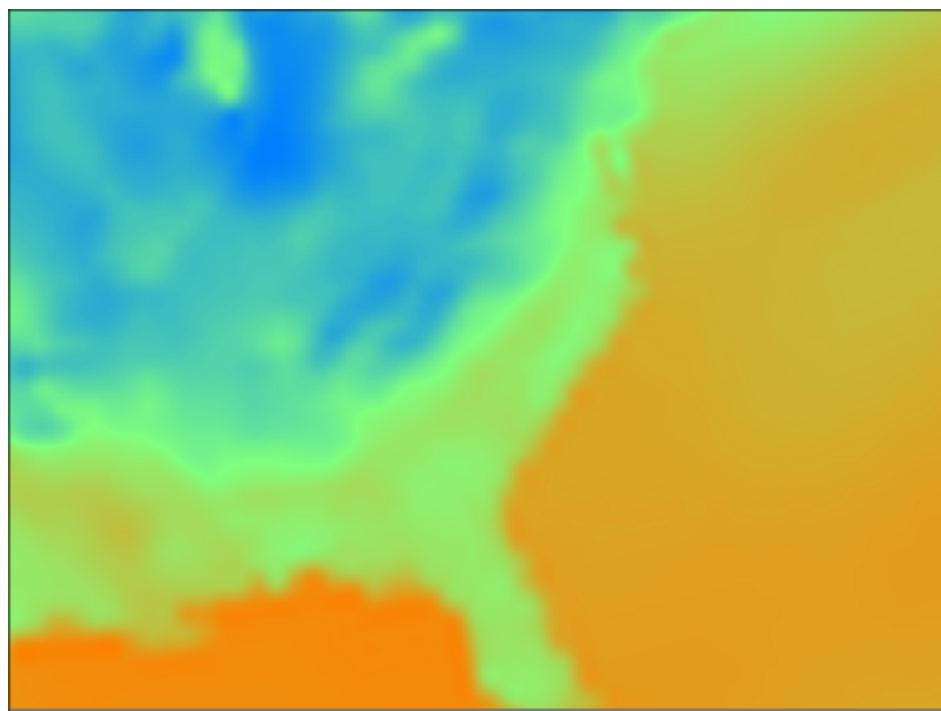
The *metgrid* program

- Horizontally interpolate meteorological
- data (extracted by *ungrib*) to simulation domains (defined by *geogrid*)
 - Masked interpolation for masked fields
 - Can process both isobaric and native vertical coordinate data sets
- Rotate winds to WRF grid
 - i.e., rotate so that U-component is parallel to x- axis, V-component is parallel to y-axis

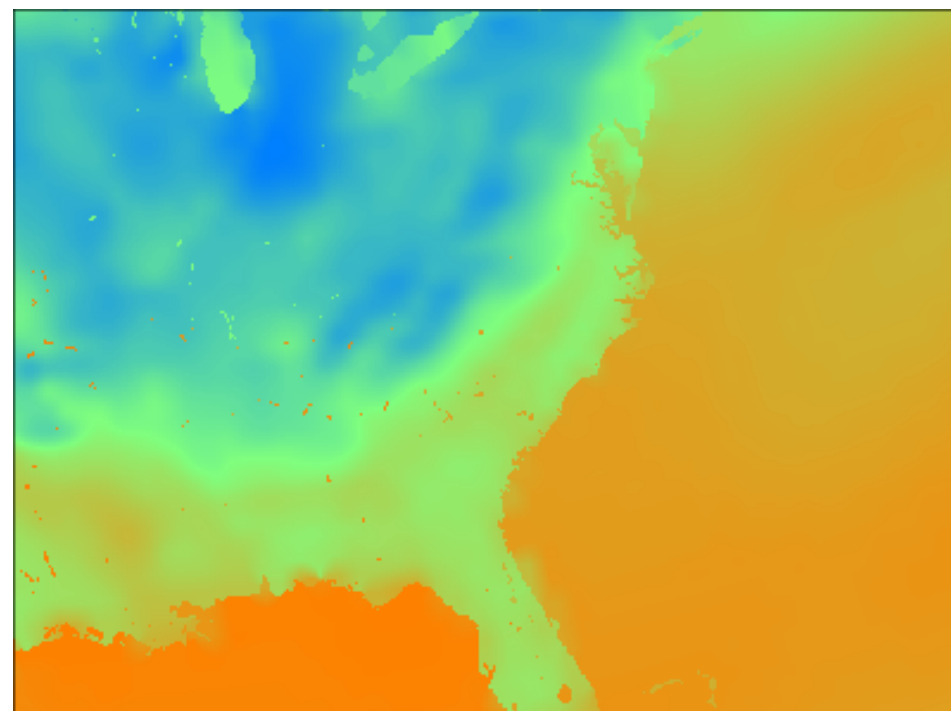
Metgrid: Masked interpolation

- Masked fields may only have valid data at a subset of grid points
 - E.g., SST field only valid on water points
- When metgrid interpolates masked fields, it must know which points are invalid (masked)
 - Can use separate mask field (e.g., LANDSEA)
 - Can rely on special values (e.g., 1×10^{30}) in field itself to identify masked grid points

Example: Masked interpolation



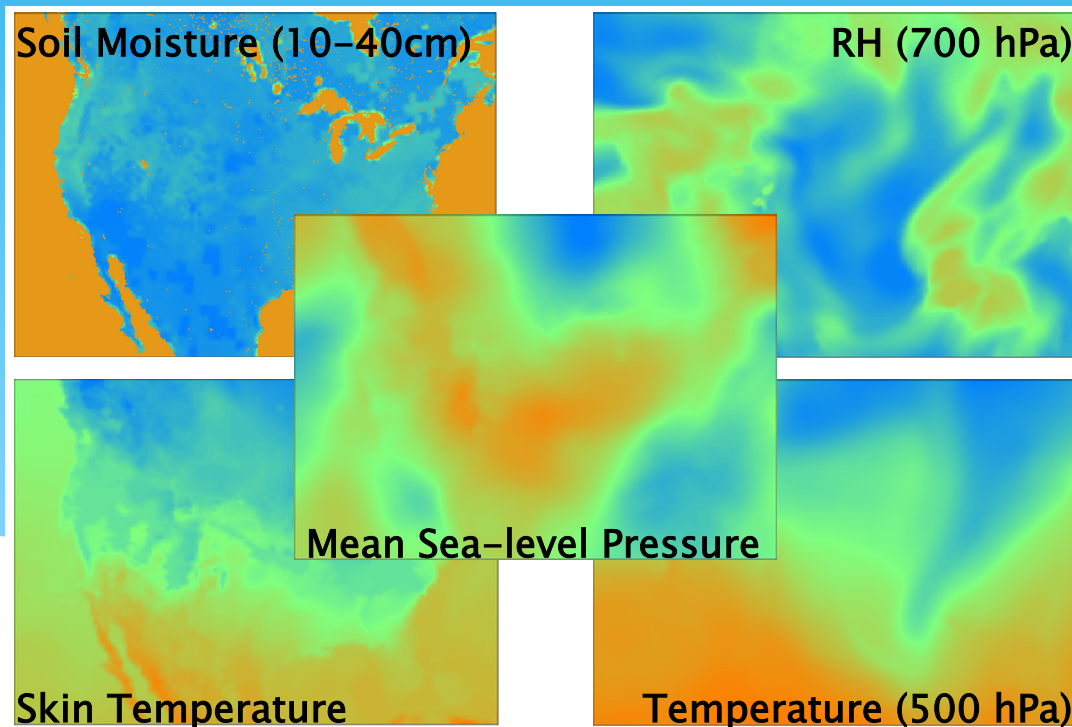
Skin temperature field interpolated from GFS 0.5-deg field with no mask using a sixteen-point interpolator



Skin temperature field interpolated using masks: GFS water points interpolated to model water points, GFS land points interpolated to model land points

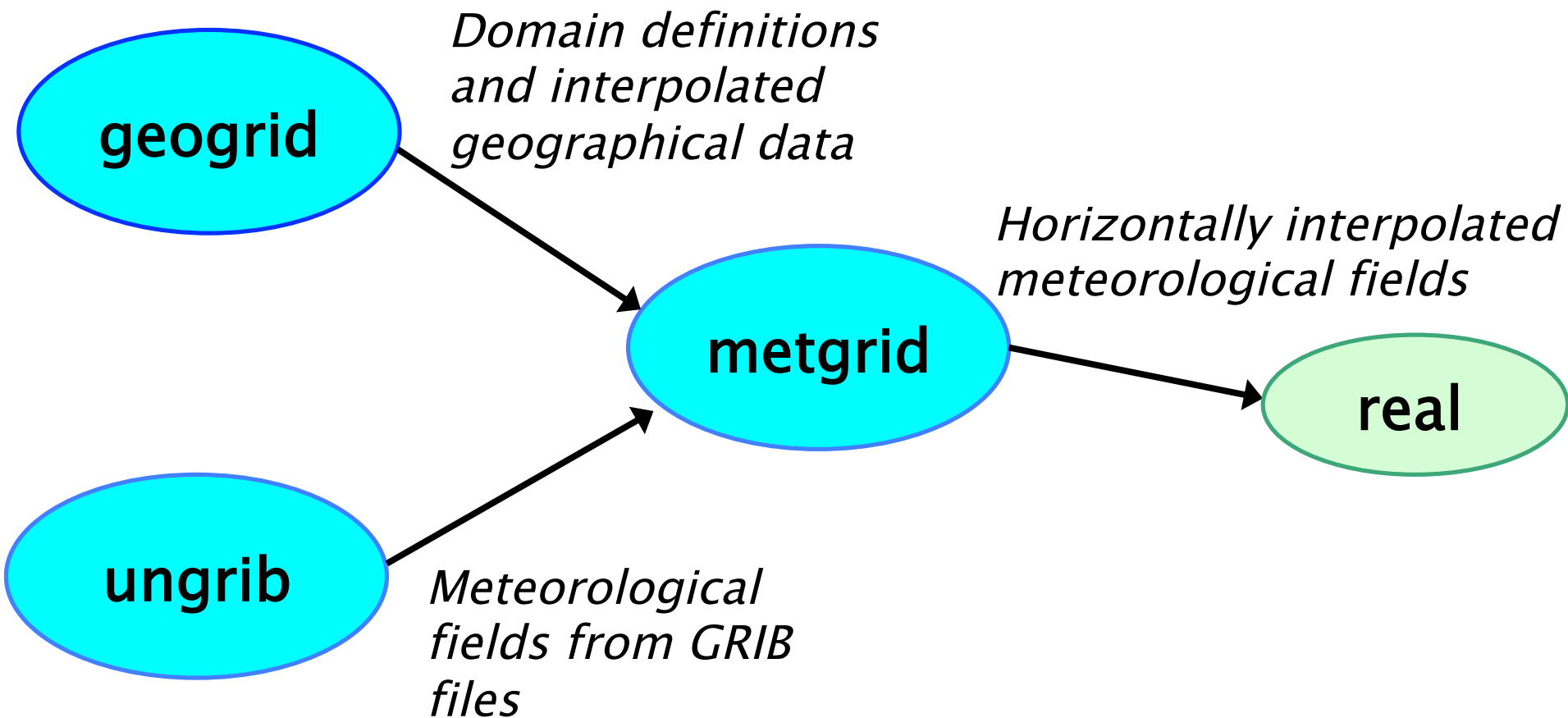
Metgrid: Model output

- For all domains; one file per time period
- Files contain static fields from geogrid plus interpolated meteorological fields
- Filenames: ARW: `met_em.don.YYYY-MM-DD_HH:mm:ss.nc`
(where *n* is the domain ID number)



WPS summary

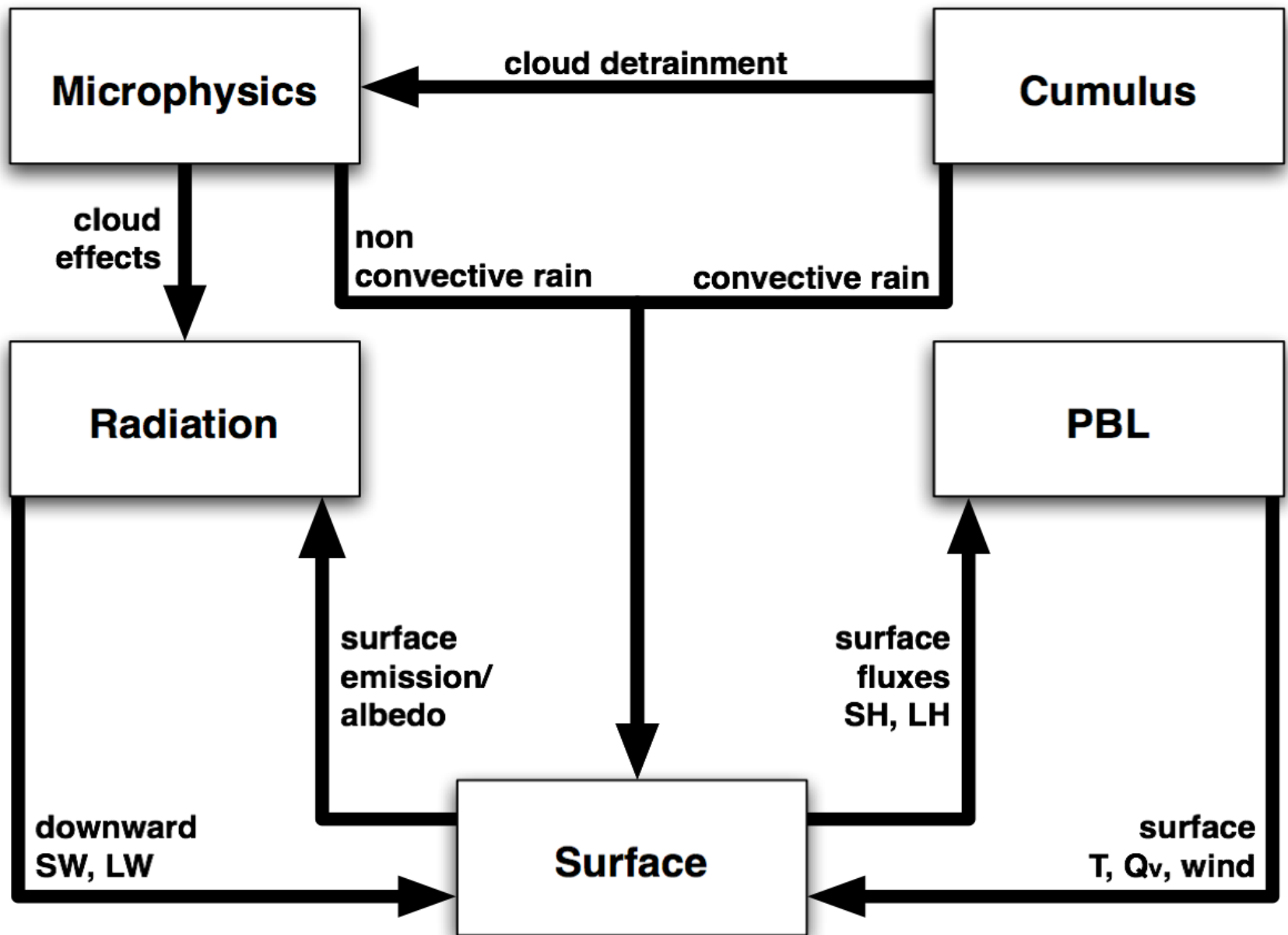
Vertical interpolation to WRF sigma levels is performed in the real program



WRF physics

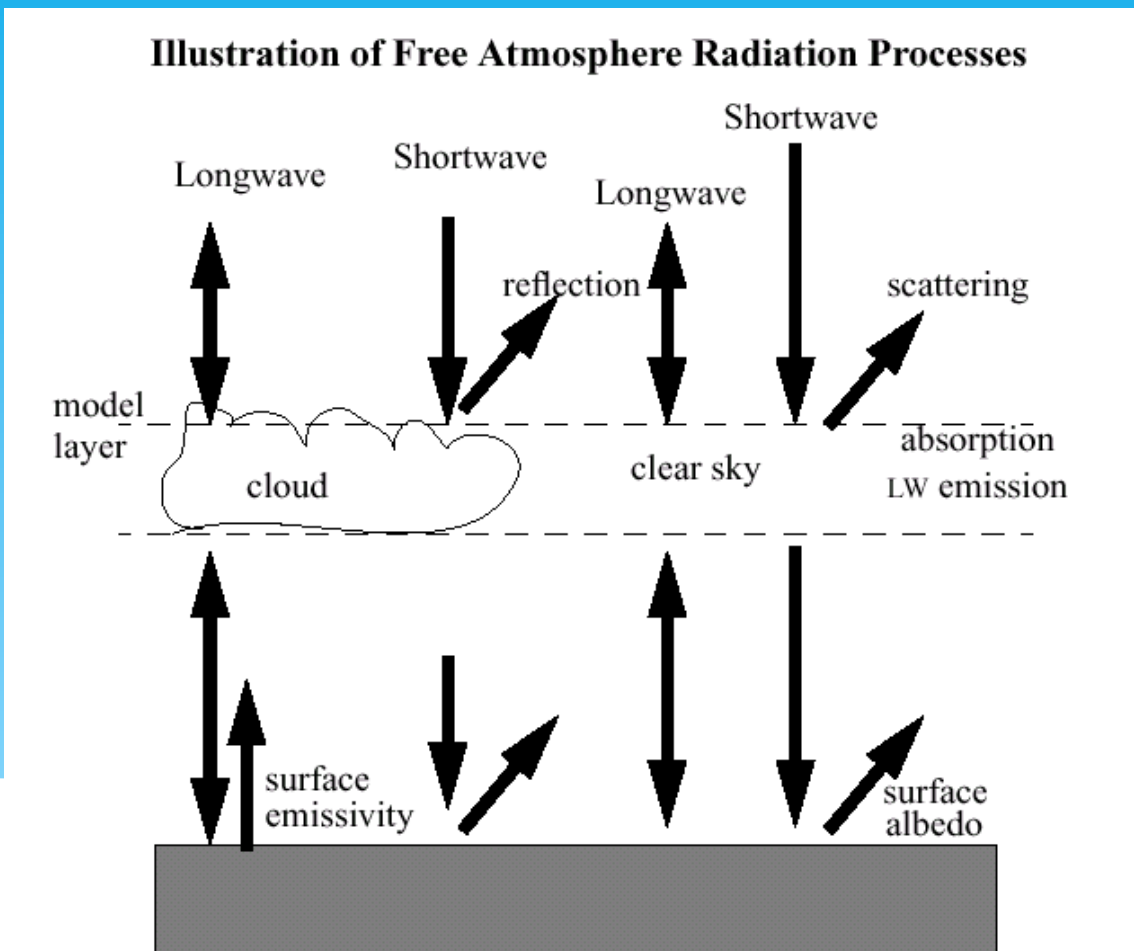
- Radiation
 - Longwave (ra_lw_physics)
 - Shortwave (ra_sw_physics)
- Surface
 - Surface layer (sf_sfclay_physics)
 - Land/water surface (sf_surface_physics)
- PBL (bl_pbl_physics)
- Turbulence/Diffusion (diff_opt, km_opt)
- Cumulus parameterization (cu_physics)
- Microphysics (mp_physics)

WRF physics – direct interaction of parameterizations



Radiation

Provides atmospheric temperature tendency profiles and surface radiative fluxes



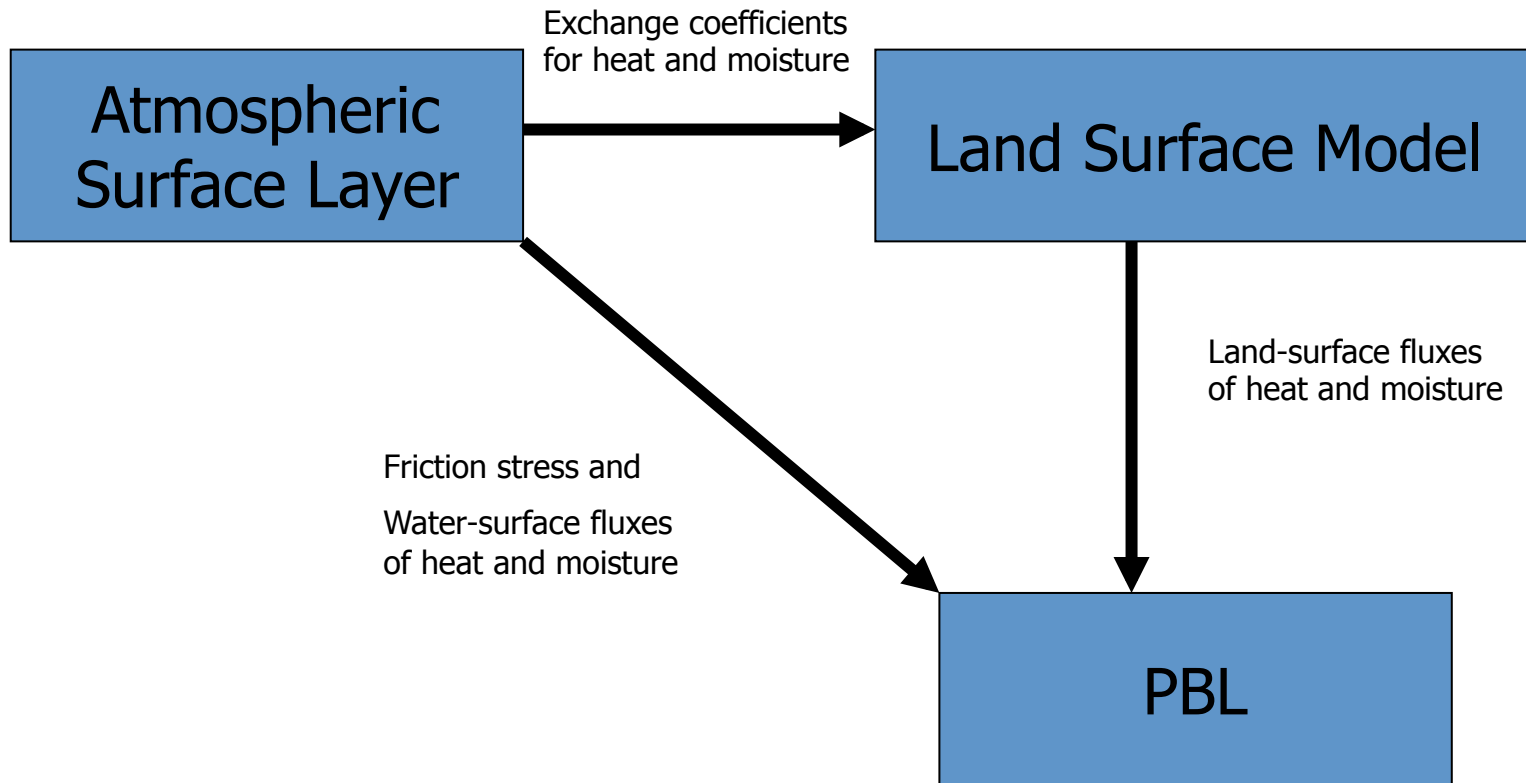
Long wave radiation

- Compute clear-sky and cloud upward and downward radiation fluxes
 - Consider IR emissions from model layers
 - Surface emissivity based on land-type
 - Flux divergence leads to cooling in a model layer
 - Downward flux at surface is important in land energy budget
 - IR radiation generally leads to cooling in clear air (~ 2 K/day), stronger cooling at cloud tops and warming at cloud base

Short wave radiation

- Computes clear-sky and cloudy solar fluxes
- Includes annual and diurnal solar cycles
- Most schemes consider downward and upward (reflected) fluxes
 - Note that the Dudhia scheme has only downward fluxes
- Primarily a warming effect in clear sky
- Important component of the surface energy balance

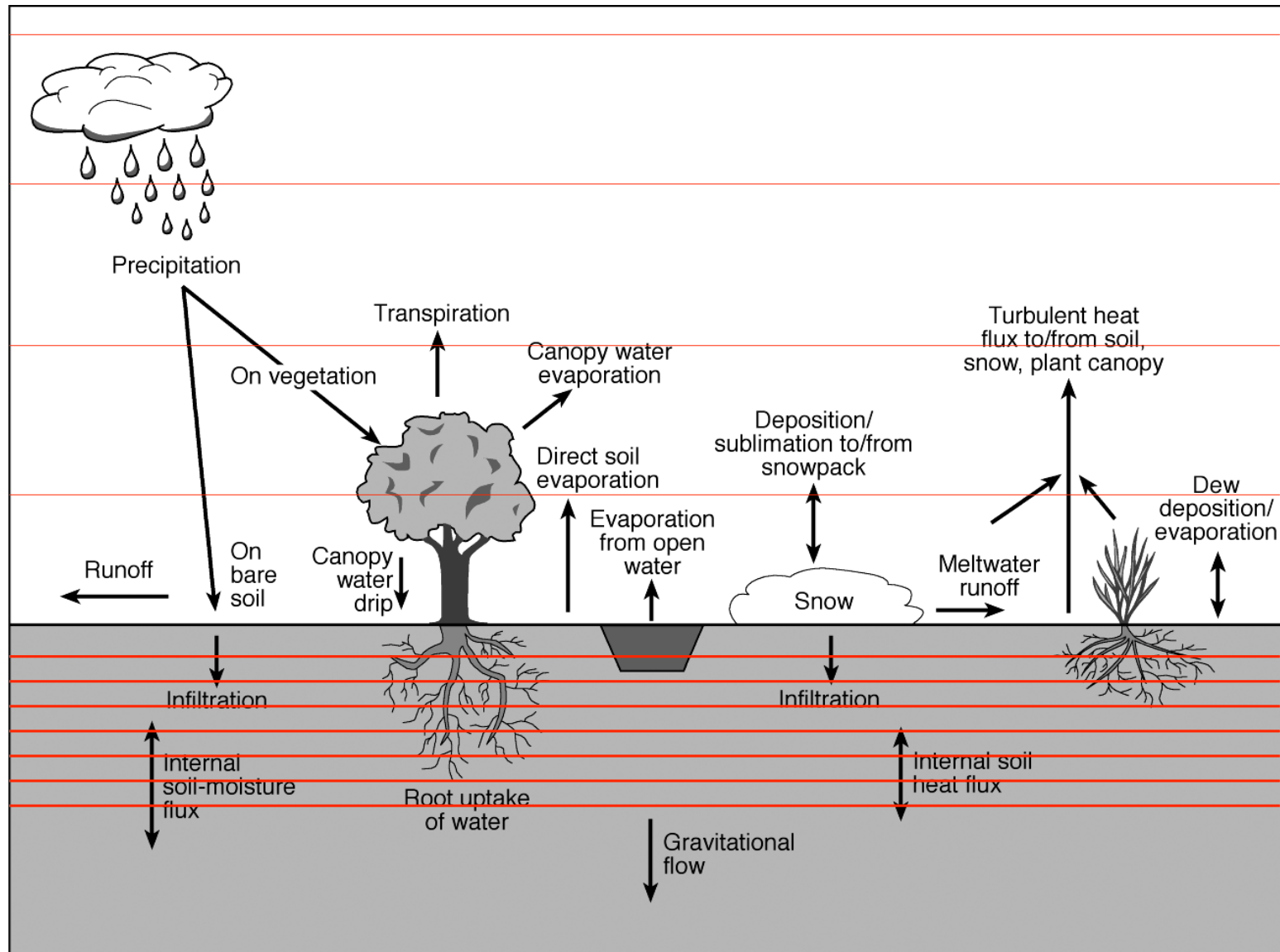
Surface physics components



WRF surface layer options

- Use similarity theory to determine the exchange coefficients and diagnostics of 2m T and q and 10m winds
- Provide exchange coefficients to land-surface models
- Provide friction velocity to PBL schemes
- Provide surface fluxes over water points
- Schemes have variations in stability functions and roughness lengths

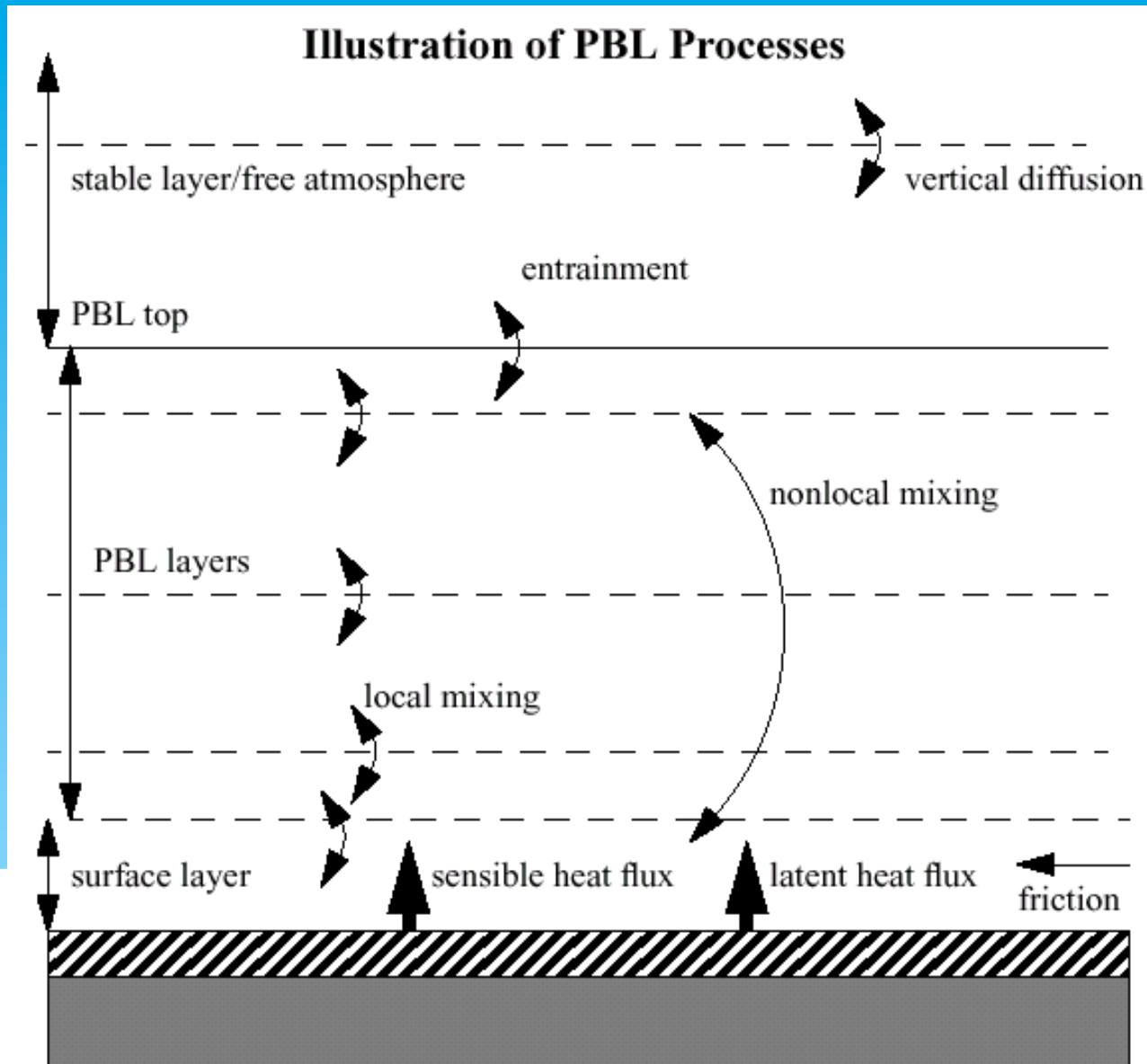
WRF land-surface models



WRF land-surface models

- Driven by surface energy and water fluxes
- Predicts soil temperature and soil moisture in layers (4 for Noah and NoahMP, 6 for RUC, 2 for PX and 3 for SSiB)
- Predicts snow water equivalent on ground. May be in layers (NoahMP, RUC, and SSiB)
- May predict canopy moisture only (Noah, RUC) or temperature only (SSiB) or both (NoahMP)

Planetary boundary layer



WRF PBL options

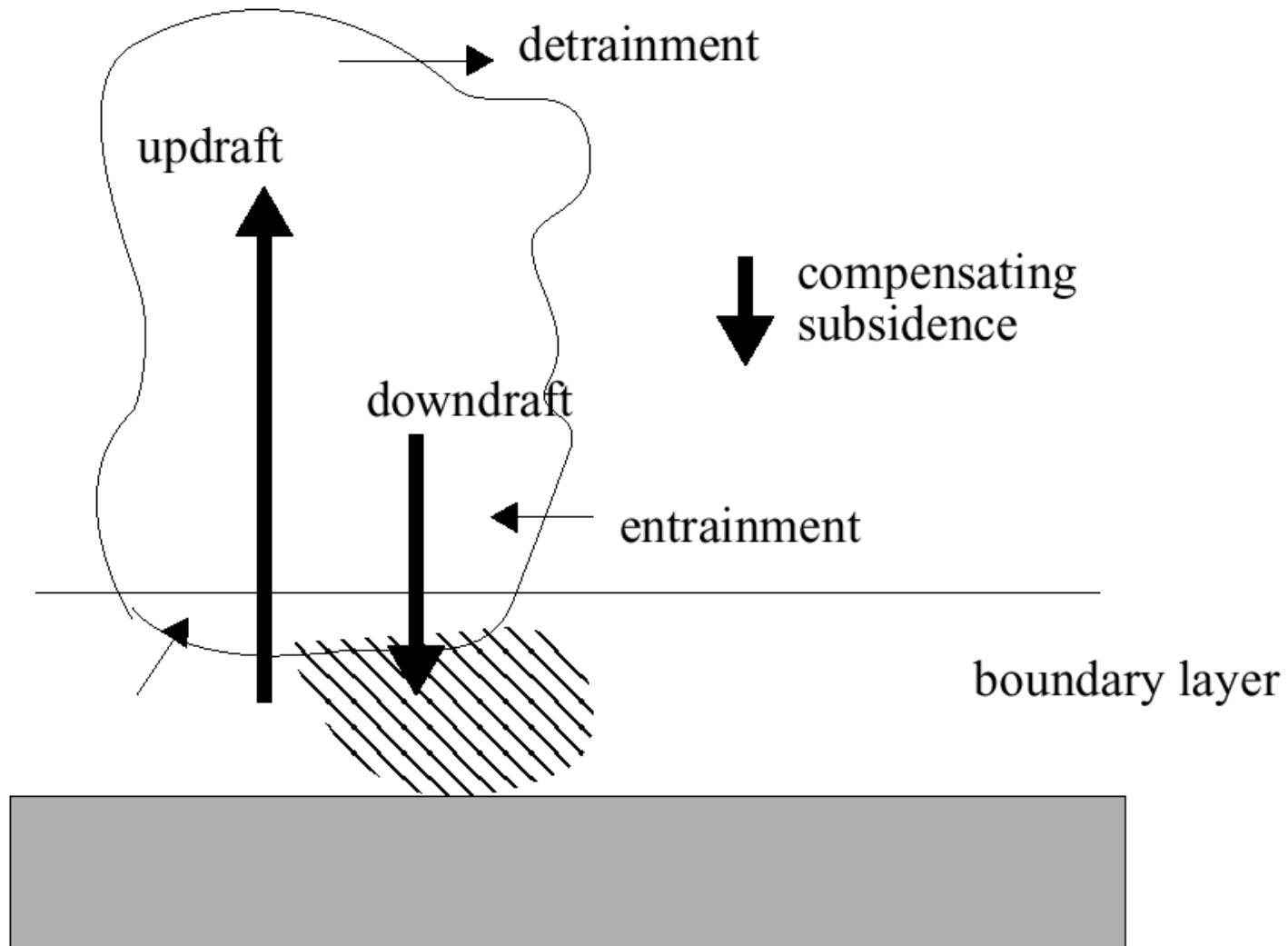
- Purpose is to distribute surface fluxes with boundary layer eddy fluxes and to allow for PBL growth by entrainment
- Classes of PBL schemes are:
 - Turbulent kinetic energy prediction (Mellor-Yamada Janjic, MYNN, Bougeault-Lacarre, TEMF, QNSE, CAM UW)
 - Diagnostic non-local (YSU, GFS, MRF, ACM2)
- Above the PBL all these schemes also do vertical diffusion due to turbulence

WRF PBL options

- PBL schemes can be used for most grid sizes when surface fluxes are present
- Lowest level should be in the surface layer
 - Important for surface (2m, 10m) diagnostic interpolation
- With ACM2, GFS and MRF schemes, lowest full level should be 0.99 or 0.995, not too close to 1
- TKE schemes can use thinner surface layers
- Assumes that PBL eddies are not resolved
- At grid size $dx \ll 1\text{km}$ this assumption breaks down
 - Can use 3d diffusion instead of a PBL scheme in WRF Version 3 (coupled to surface physics)
 - Works best when dx and dz are comparable

Cumulus parameterization

Illustration of Cumulus Processes



Cumulus schemes

- Used for grid columns that completely contain convective clouds
- Re-distribute air in column to account for vertical convective fluxes
 - Updrafts take boundary layer air upwards
 - Downdrafts take mid-level air downwards
- Schemes have to determine
 - When to trigger a convective column
 - How fast to make the convection act
- Clouds only activate in columns that meet certain criteria
 - Presence of some CAPE in sounding
 - Not too much convective inhibition (CIN) in sounding
 - Minimum cloud depth from parcel ascent

Microphysics schemes

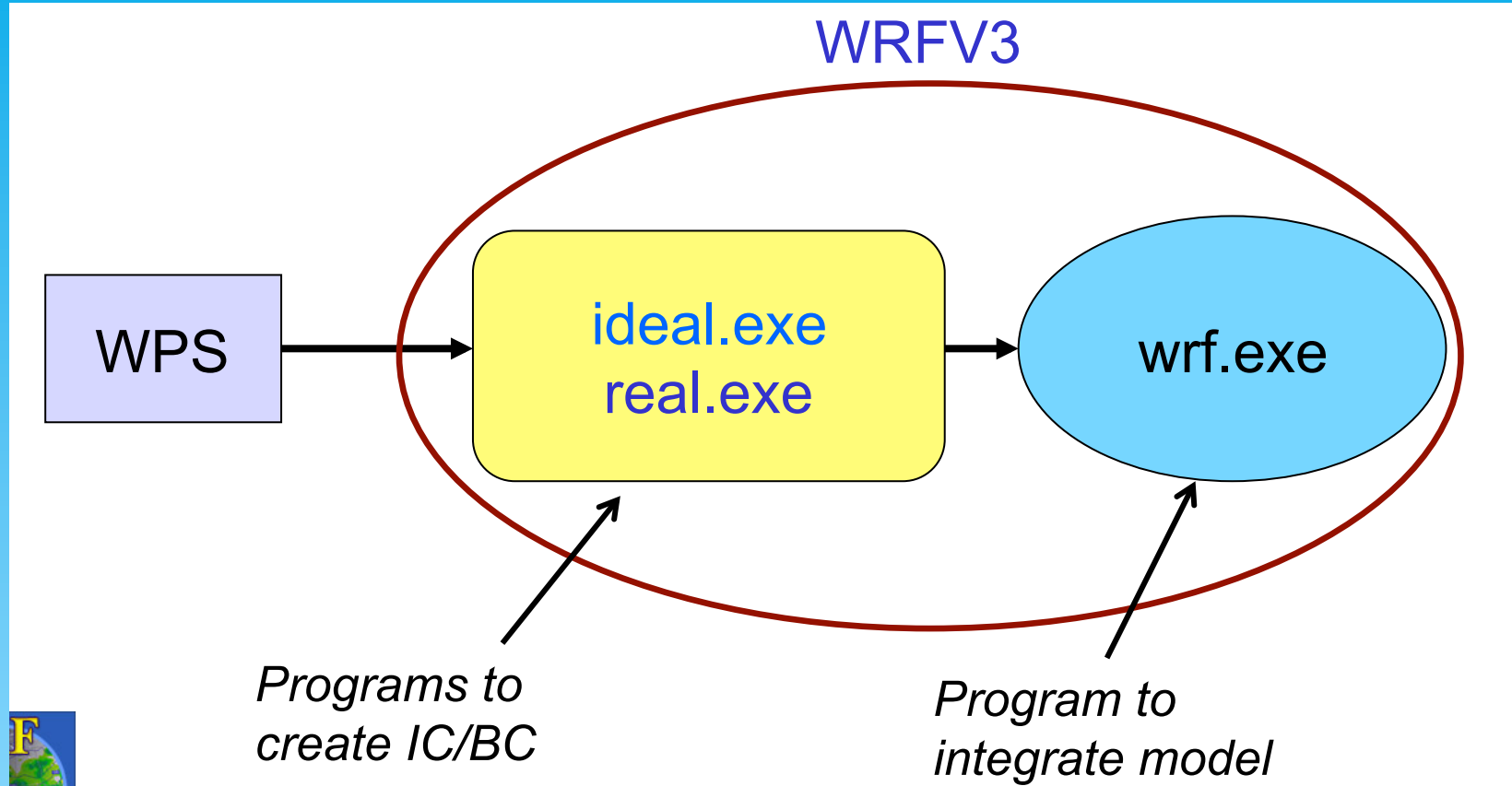
- Range of levels of sophistication
 - Warm rain (i.e. no ice) – idealized
 - Simple ice (3 arrays)
 - Mesoscale (5 arrays, no graupel)
 - Cloud scale single-moment (6 arrays, with graupel)
 - Double moment (8-13 arrays)
 - Spectral Bin (120-240 arrays)
- Latent heat release from
 - Condensation, evaporation, deposition, sublimation, freezing, and melting
- Particle types
 - Cloud water, raindrops, ice crystals, snow, graupel, hail
- Processes
 - Aggregation, accretion, growth, and fall-out

Microphysics: Single vs. double moment schemes

- Single-moment schemes have one prediction equation for mass (kg/kg) per species (Q_r , Q_s , etc.) with particle size distribution being derived from fixed parameters
- Double-moment (DM) schemes add a prediction equation for number concentration ($\text{\#/kg}$) per DM species (N_r , N_s , etc.)
 - DM schemes may only be double-moment for a few species
 - DM schemes allow for additional processes such as size-sorting during fall-out and sometimes aerosol (CCN) effects

Running the WRF model

WRF system flowchart



Running the WRF model

- cd to run/ or one of the test case directories
- Move or link WPS output files to the directory for real-data cases
- Edit `namelist.input` file for the appropriate grid and times of the case
- Run a initialization program (`real.exe`)
- Run model executable, `wrf.exe`

What is a namelist?

- A Fortran namelist contains a list of runtime options for the code to read in during its execution. Use of a namelist allows one to change runtime configuration without the need to recompile the source code.
- Fortran namelist has very specific format, so edit with care:

```
&namelist-record      - start  
/                      - end
```

- As a general rule:
 - Multiple columns: domain dependent
 - Single column: value valid for all domains
- A namelist file may contain a number of records

What is a namelist?

namelist record **&time_control**

```
run_days      = 0,  
run_hours     = 24,  
run_minutes   = 0,  
run_seconds   = 0,  
start_year    = 2000, 2000, 2000,  
start_month   = 01, 01, 01,  
start_day     = 24, 24, 24,  
start_hour    = 12, 12, 12,  
start_minute  = 00, 00, 00,  
start_second  = 00, 00, 00,  
end_year      = 2000, 2000, 2000,  
end_month     = 01, 01, 01,  
end_day       = 25, 25, 25,  
end_hour      = 12, 12, 12,  
end_minute    = 00, 00, 00,  
end_second    = 00, 00, 00,  
interval_seconds = 21600  
history_interval = 180, 60, 60  
frames_per_outfile = 1000, 1000, 1000,  
restart_interval = 360,  
restart       = .true.,
```

domain 1 option

nest options

How to check model output?

- Use ncdump:
 - `ncdump -h wrfout_do?_<date>`
to get the header information
 - `ncdump -v Times wrfout_do?_<date>`
to check output time
 - `ncdump -v Uwrfout_do?_<date>`
to check a particular variable (U, in this case)
- Use ncview to quickly plot variables
- Plethora of other software tools
 - NCL
 - RIP4
 - Grads
 - Python

ISOR/Belgingur WOD system

Historical overview in one slide

SARWeather ?

Ólafur Ragnvaldsson Credit: 2586 (+1000)
[Edit Account] [Buy More]

Request New Forecast List of Forecasts

Logout Send Feedback

Request Forecast

Title

Latitude N16°36'

Longitude W22°55'

Period

Start 2015-05-12 09:00

End 2015-05-12 21:00

Length 12 hr

Cost 19 cr

Data **New forecast from 2015-05-12 00:00**

Type

Size	Res.	Cost [cr]
☐ 30 km	1 km	5+0.5/hr
☒ 66 km	1 km	5+1.2/hr
☐ 138 km	1 km	5+2.5/hr
☐ 130 km	3 km	5+0.3/hr
☐ 256 km	3 km	5+0.8/hr
☐ 544 km	3 km	5+2.0/hr
☐ 547 km	9 km	5+0.2/hr
☐ 1015 km	9 km	5+0.4/hr
☐ 2005 km	9 km	5+1.0/hr

Options

☐ Aviation - Flight-level plots at additional cost

☒ Public - Visible to other users

Start Forecast for 19 cr

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Followed by a live demo

2007-2008: Lobbyism, applications, etc. etc.



2007: Flight of the SUMO



2007: Idea emerges



2009: Cash starts flowing



January 2010: Haiti



Spring 2010: USAR conference in Abu Dhabi



Spring/summer 2010: Eruption in Mt. Eyjafjallajökull



2009-2010: Code like the wind

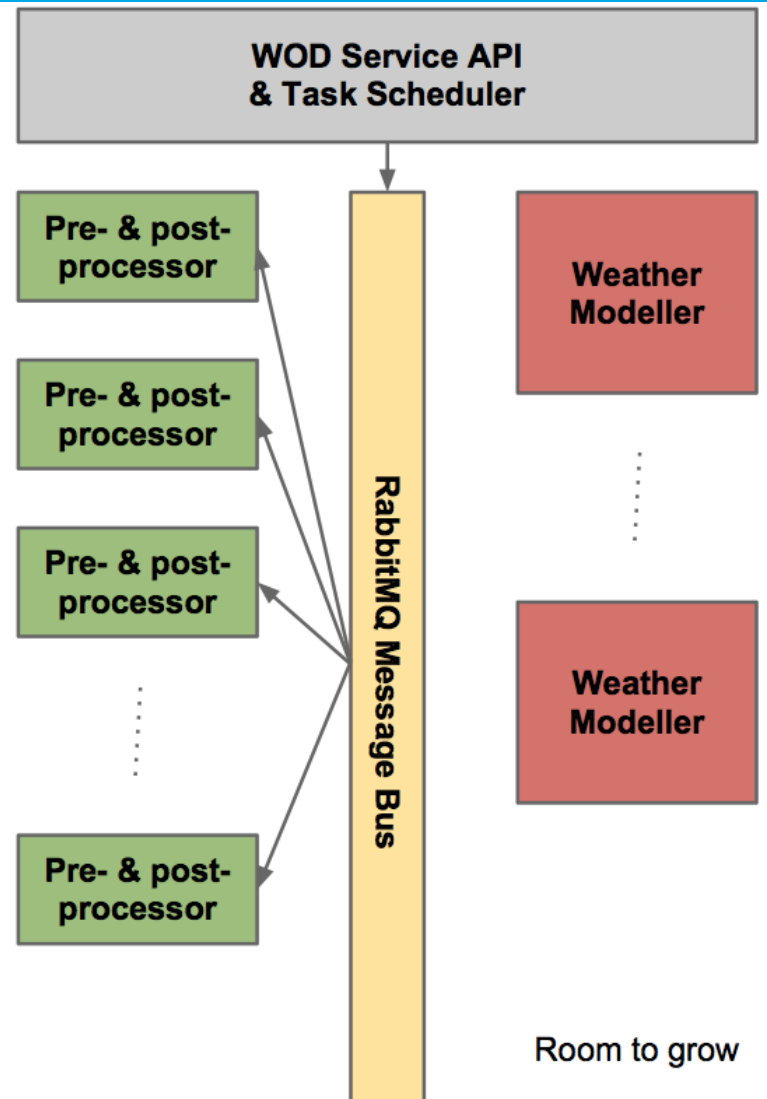


May 2010: GDACS annual meeting



WOD Workflow

1. WOD API breaks request into tasks
2. Pre-processing starts immediately
3. Weather modellers started as needed
4. Post-processing tasks run in parallel with modeller
5. Output available ASAP



Another live demo!!!

Forecast On Demand

Three layer cake

Open source
atmospheric model and
input data

Forecast On Demand
software stack

Customized Output, e.g.
Search And Rescue
(SARWeather)
Wind Energy
Road Authorities

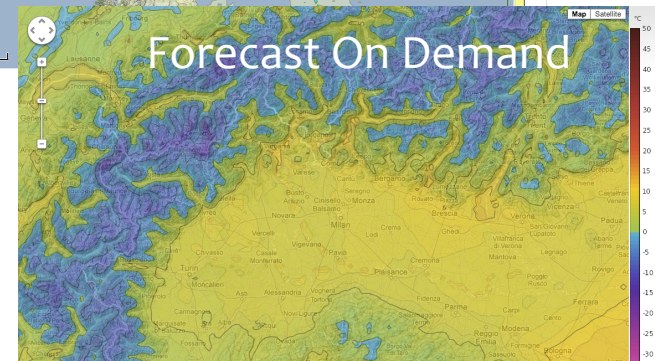
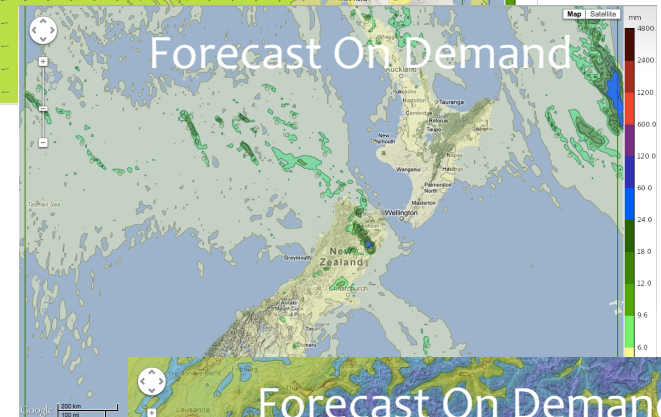
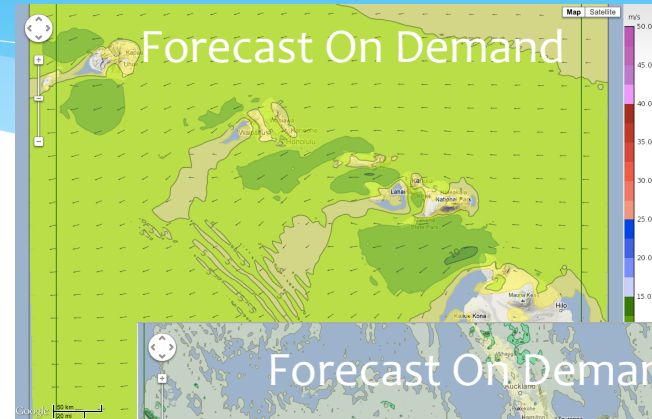
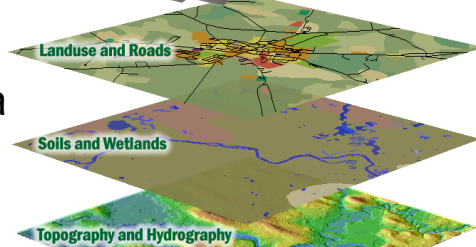
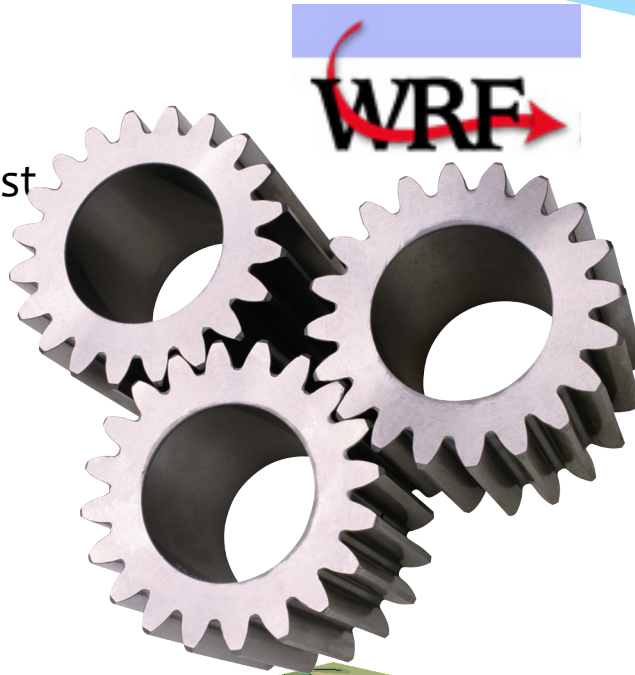


Dataflow static and dynamic data

New global forecast
every 6 hours

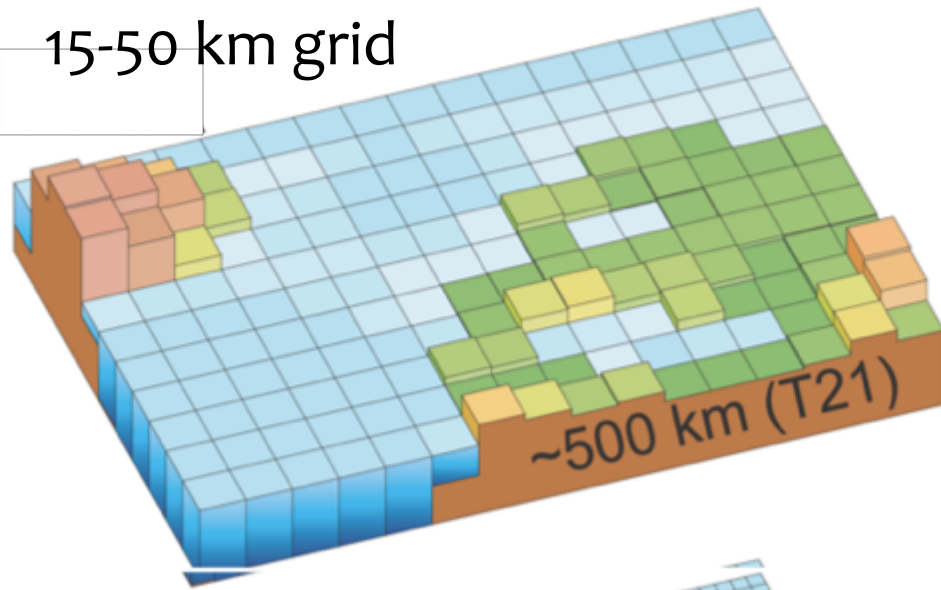


Static geographic data

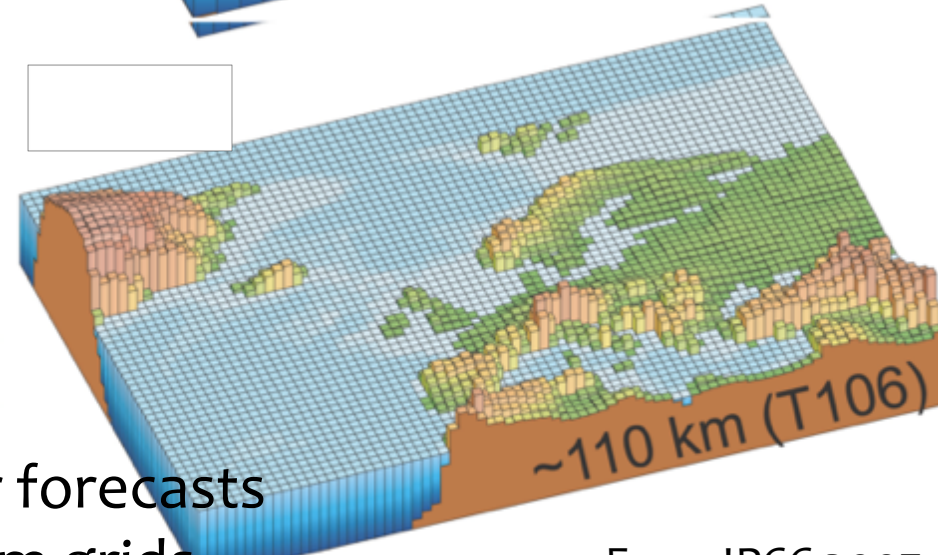
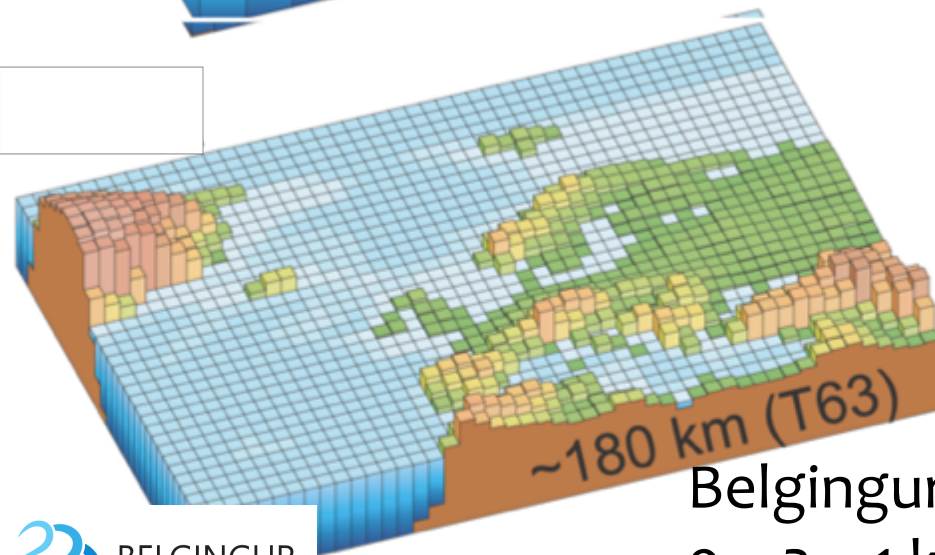
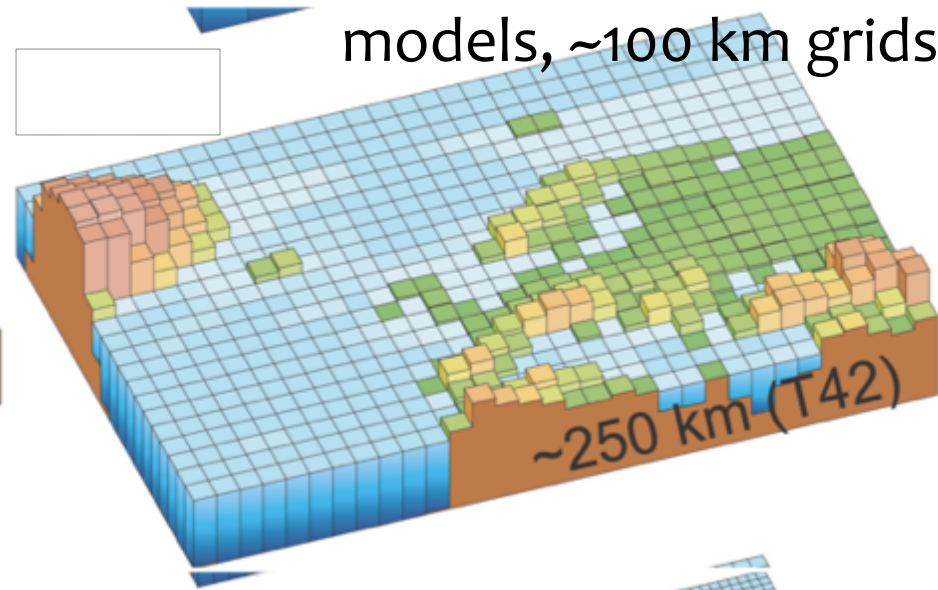


Importance of high resolution

Global forecasts
15-50 km grid



Current climate
models, ~100 km grids



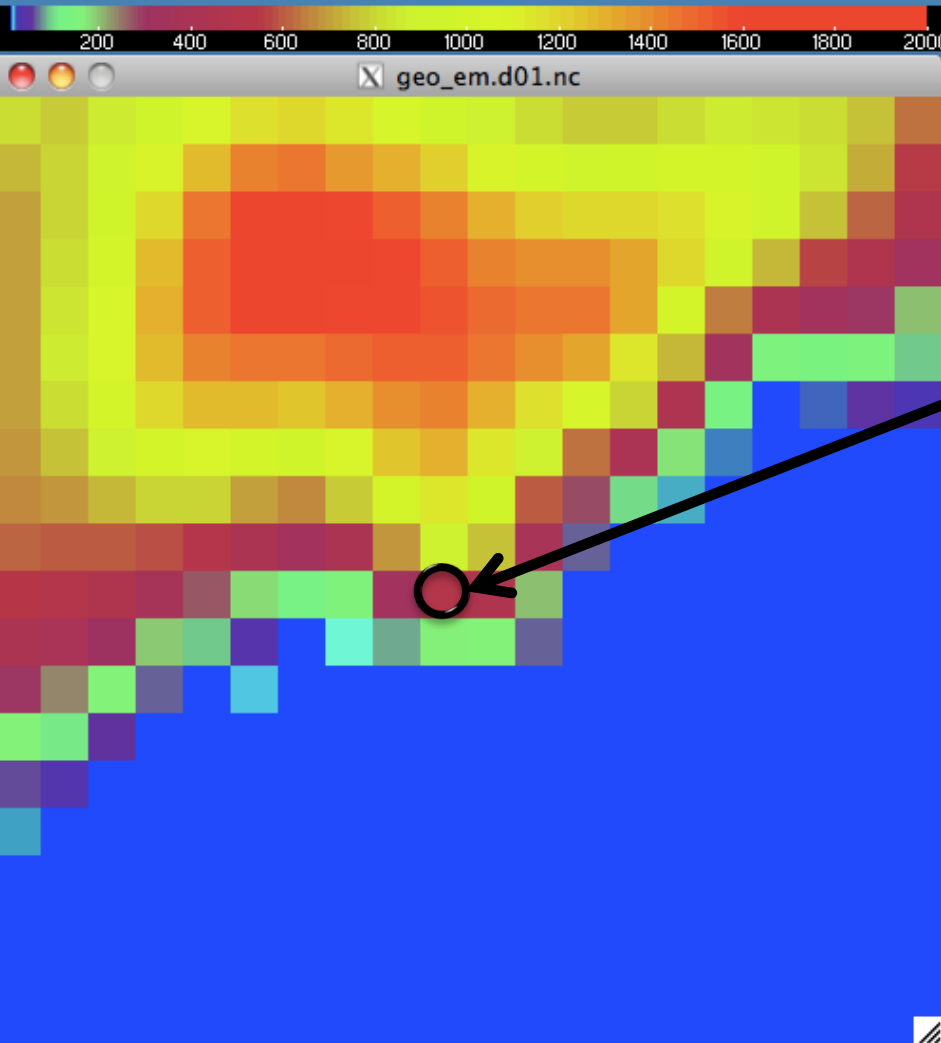
Belgingur forecasts
9 – 3 – 1 km grids

Importance of high resolution

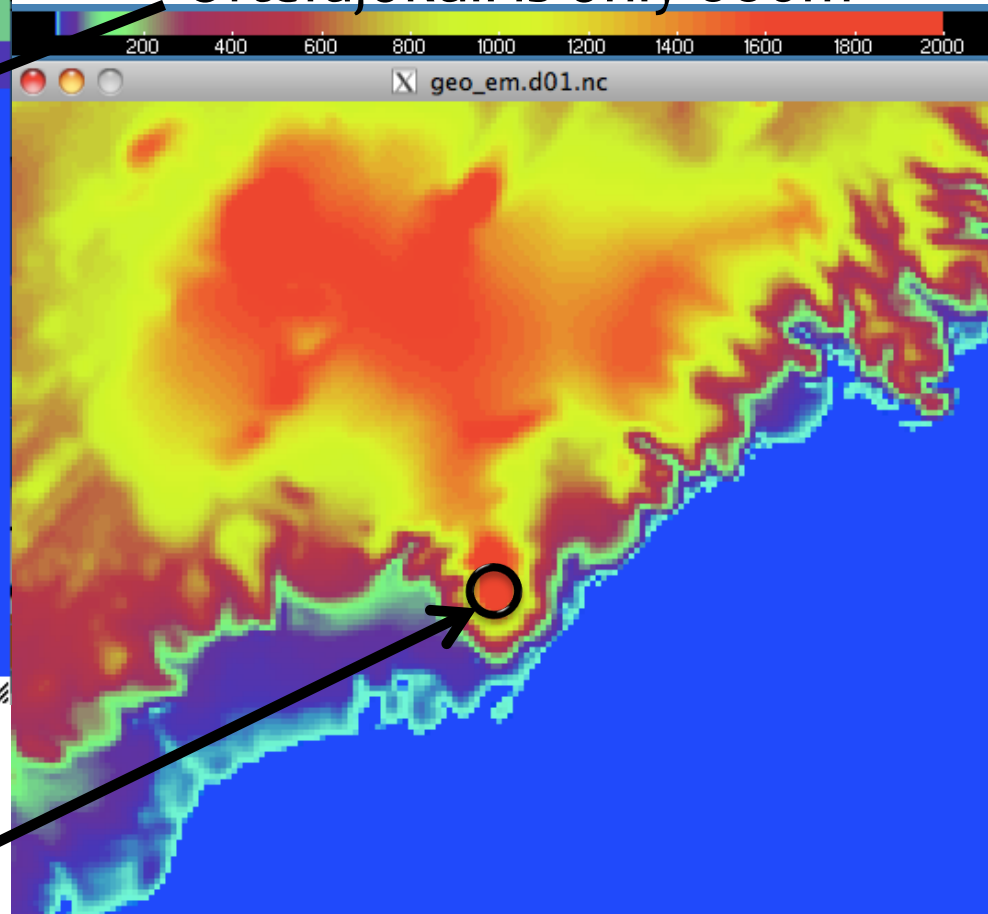


How does the weather model “see” this mountain?

Importance of high resolution

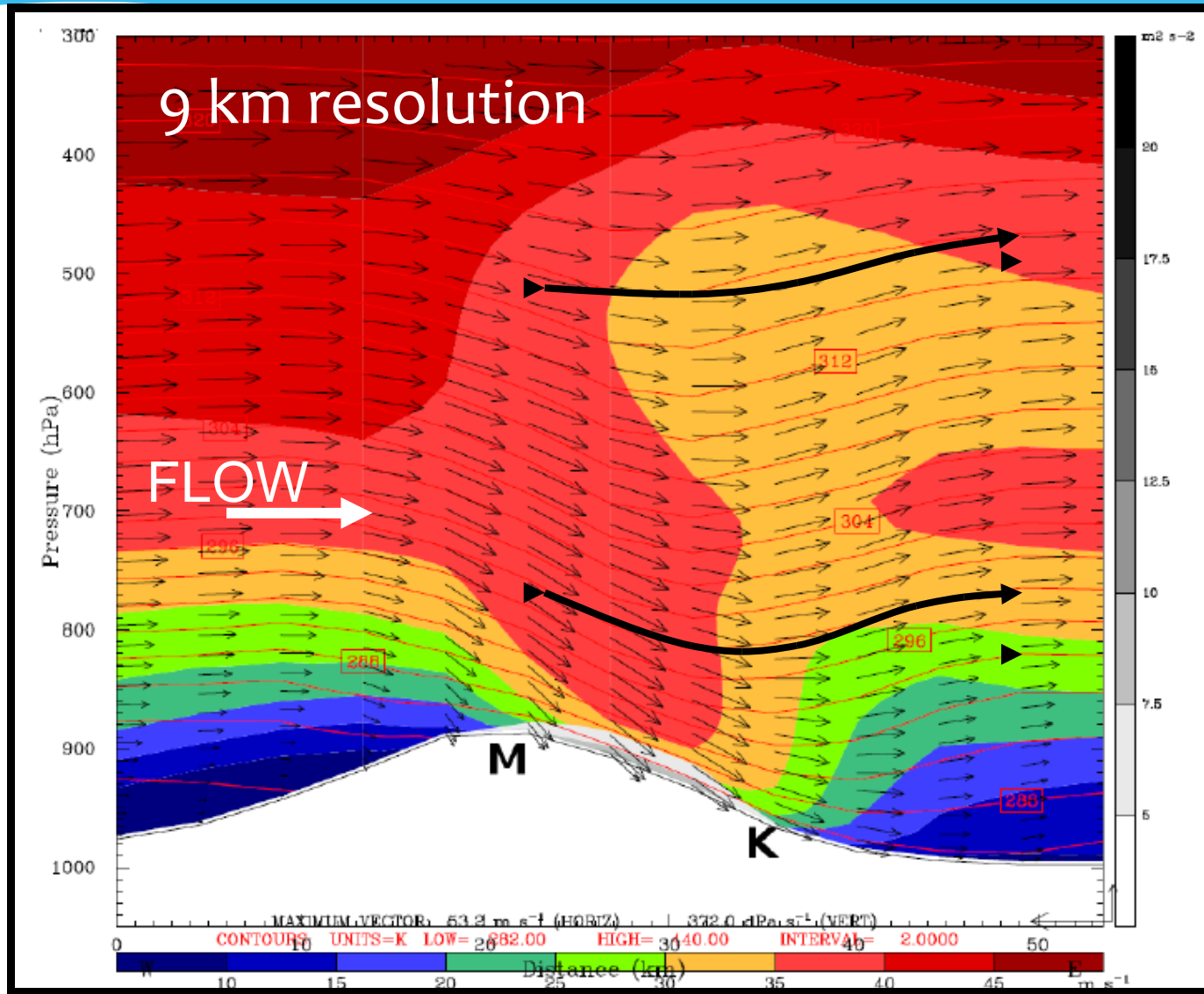


Vatnajökull icecap, max height is 1675m. Top height of Mt. Öräfajökull is only 880m



At 1km resolution the max height is 2020m. Top height of Mt. Öräfajökull is now 1945m

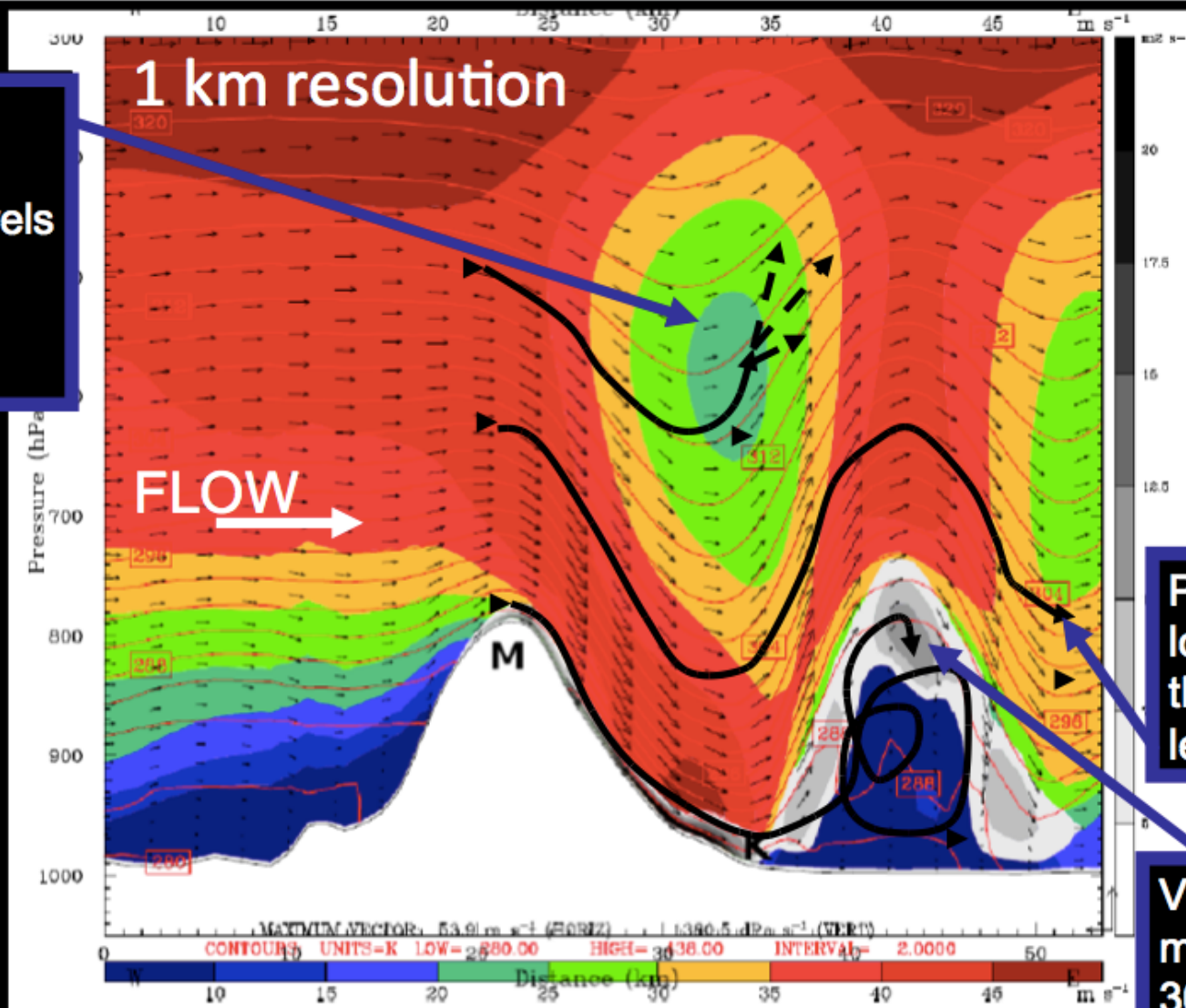
Importance of high resolution





Importance of high resolution

Vertical mixing at higher levels due to mountain waves

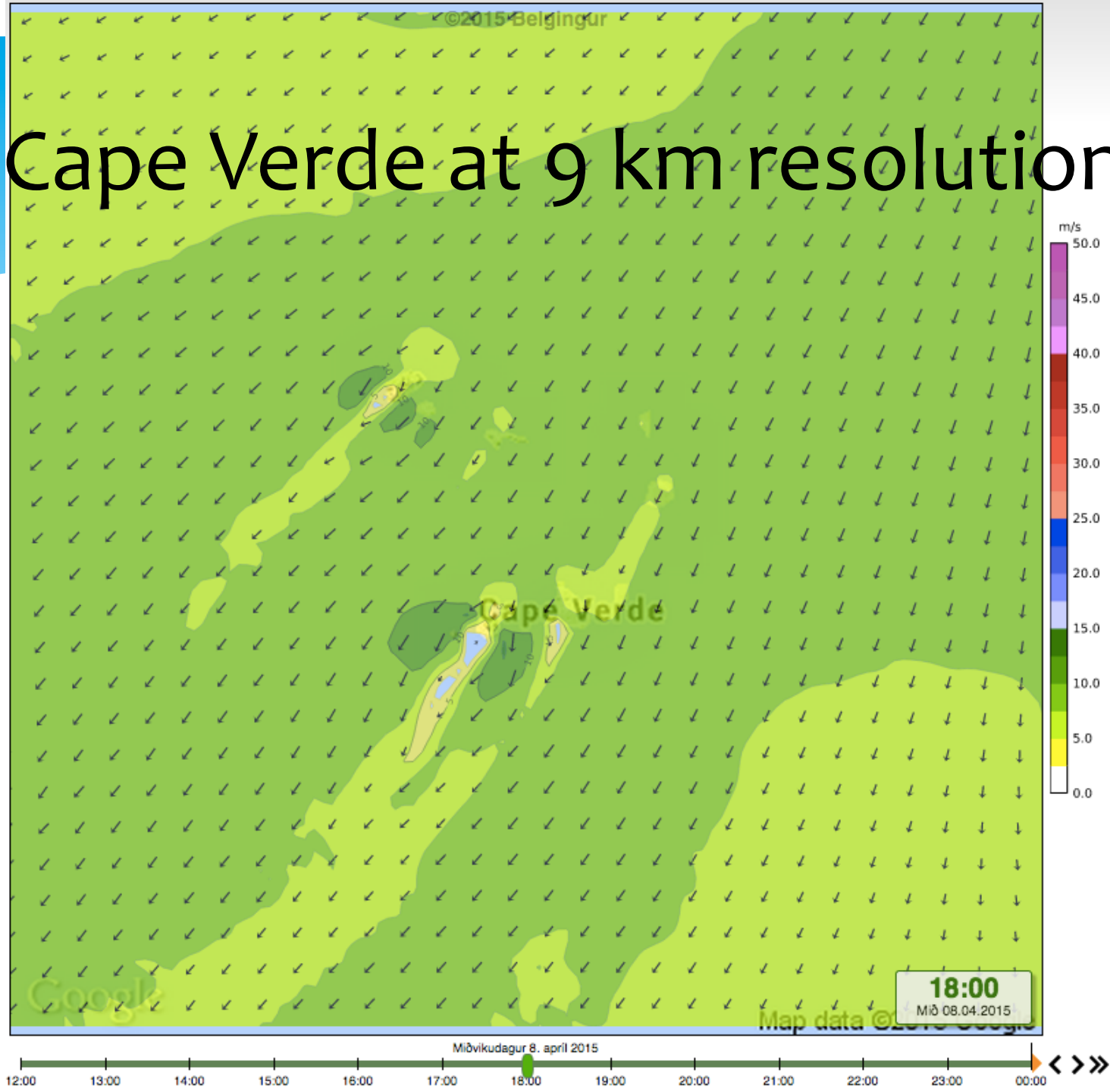


Permanent lowering of the flow level

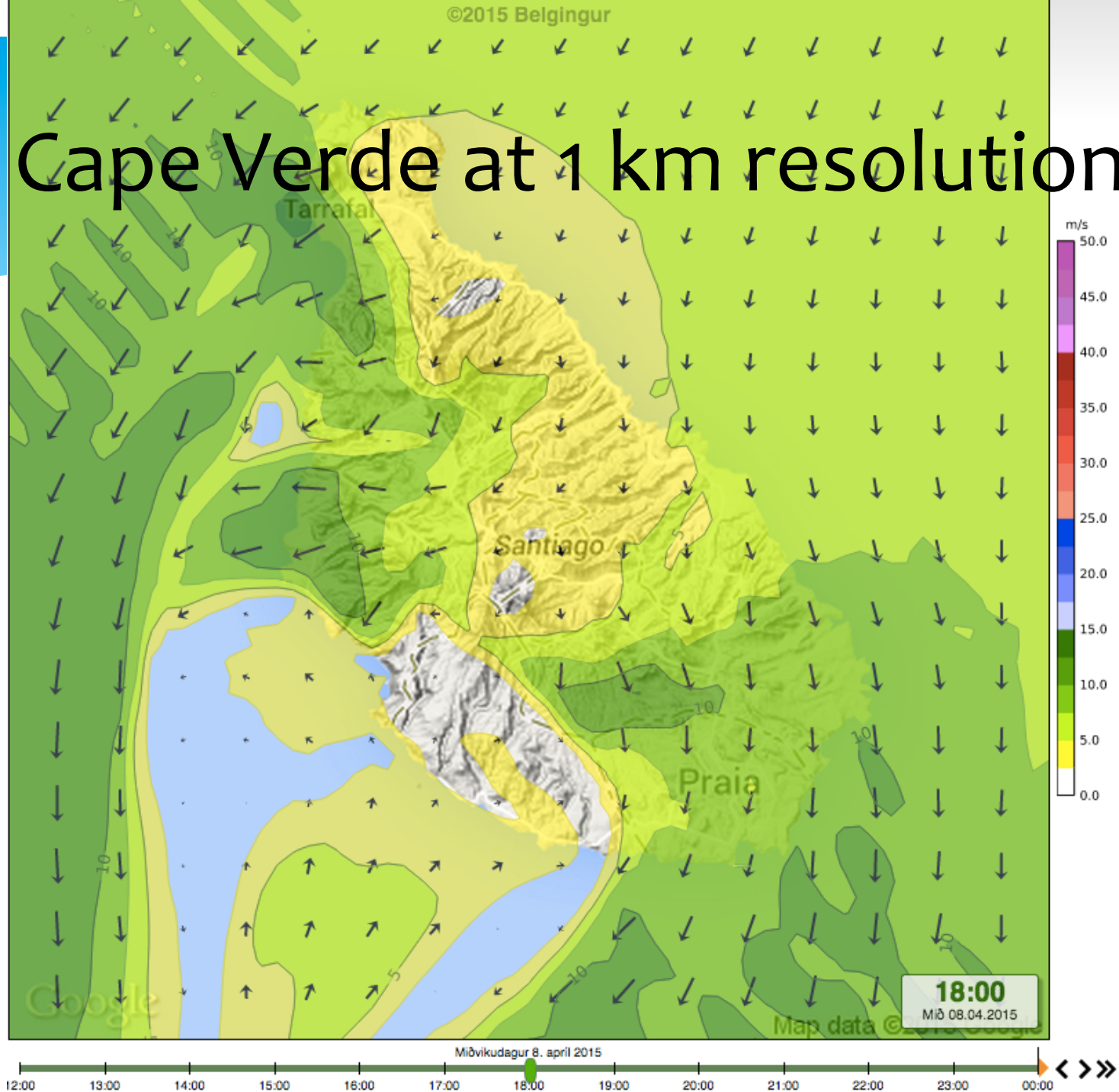
Vertical mixing in a 3000 m deep layer

None of these important features are visible at $dx=9\text{km}$, or at resolutions of many current forecast models!

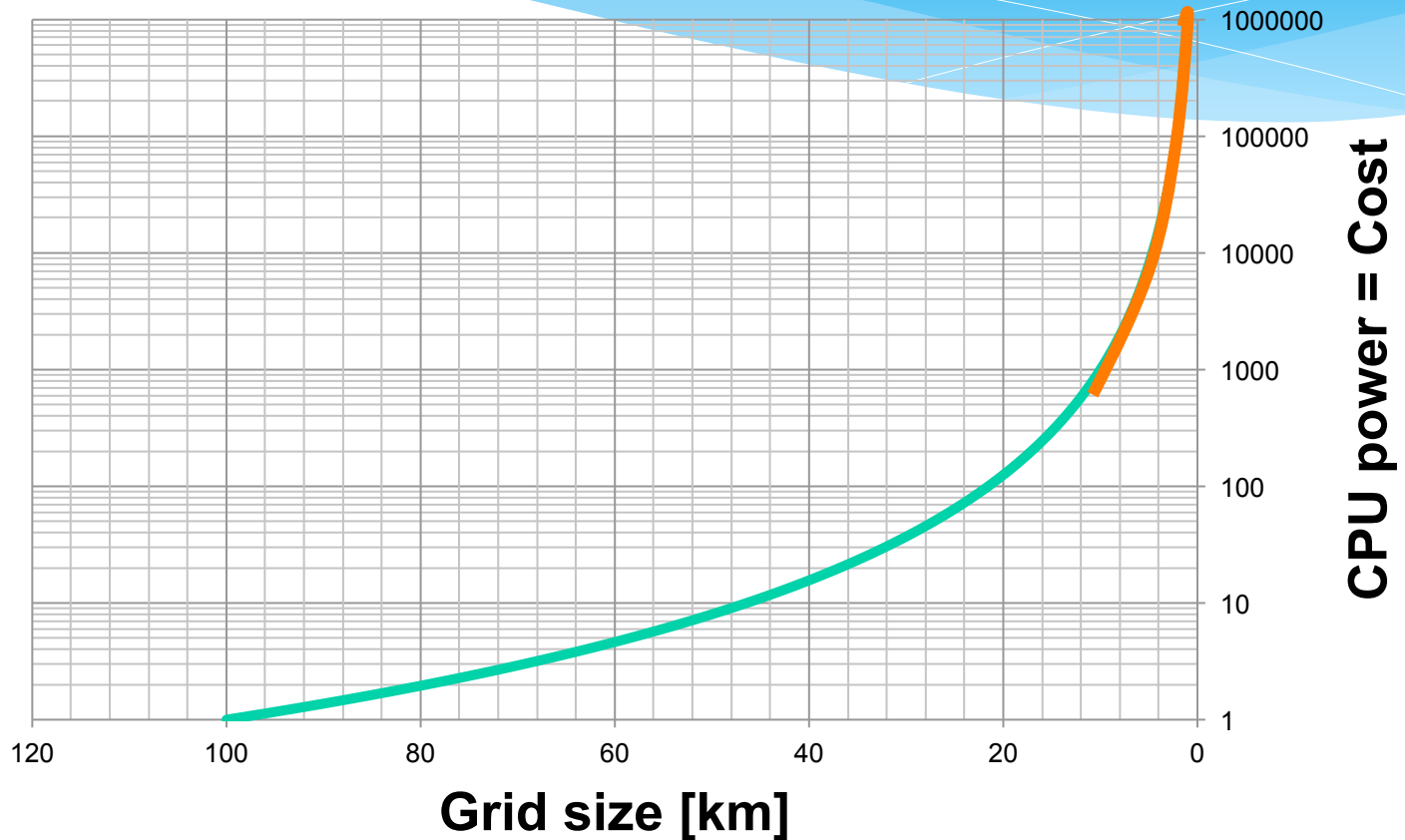
Cape Verde at 9 km resolution



Cape Verde at 1 km resolution



Why not always use 1km resolution?



Need 1000-times more CPU power to simulate a 1 km resolution forecast than a 10 km one for the same region!

The WRF-Chem model

- Open source addition to the WRF model
 - Development is led by NOAA
- Potential to simulate the coupling between dynamics, radiation and chemistry
 - Capable of both on-line and off-line modeling
- Simulate and forecast the dispersion of chemical constituents and/or other airborne pollutants
 - e.g. SO₂ and volcanic ash

SO₂ forecasts

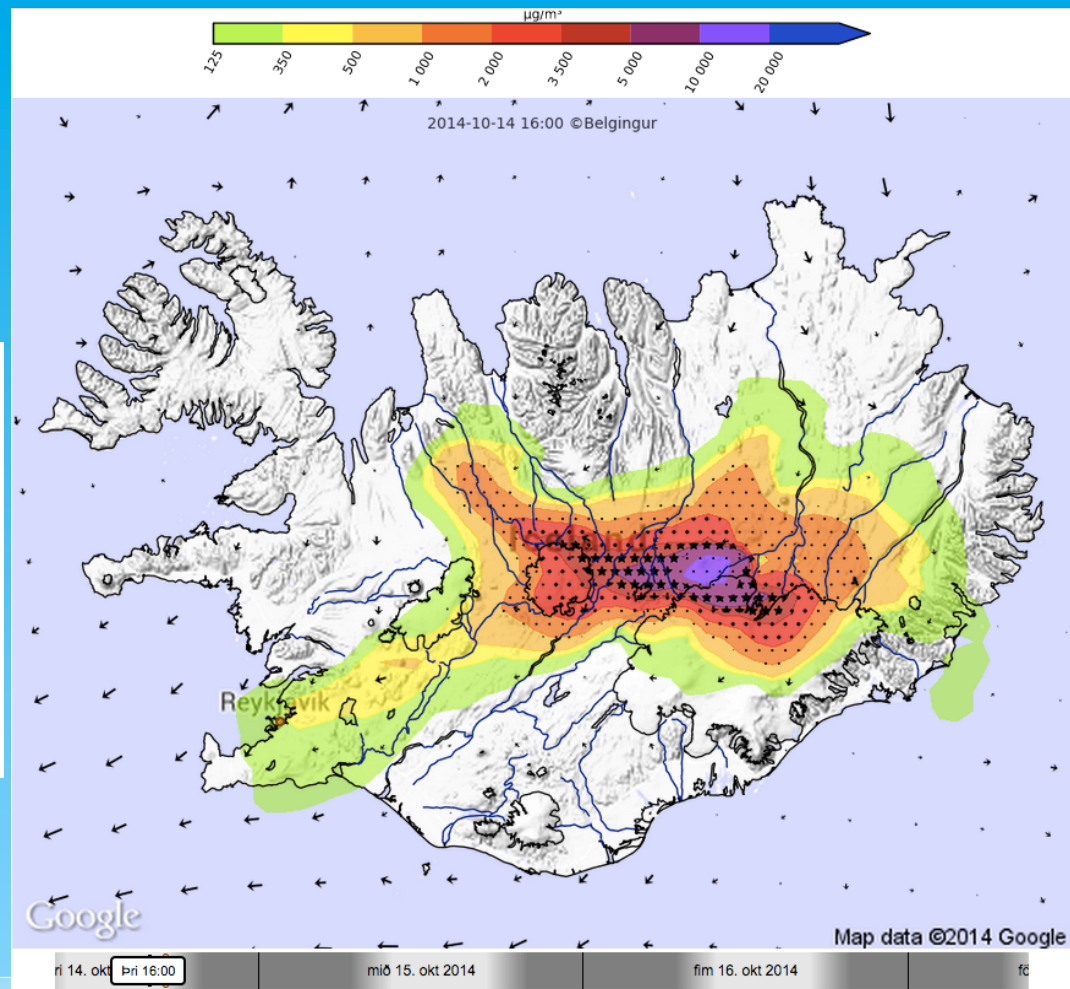
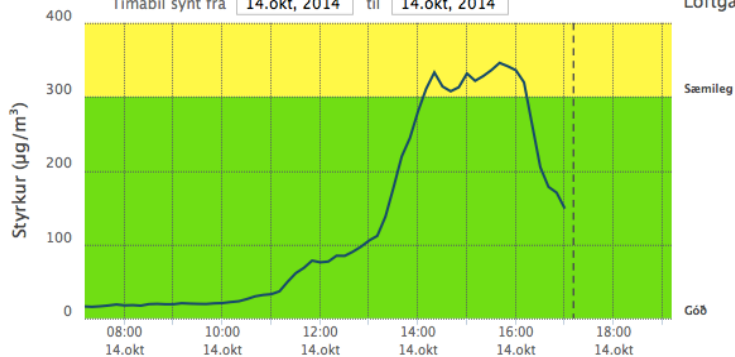
SO₂ forecast for 16 UTC
2014-10-14

Strength of SO₂ in Reykjavík is
~350 µg/m³

Norðlingaholt, Reykjavík – Brennisteinsdíoxíð (SO₂) – 10 mín. meðaltöl

Tímabil sýnt frá 14.okt, 2014 til 14.okt, 2014

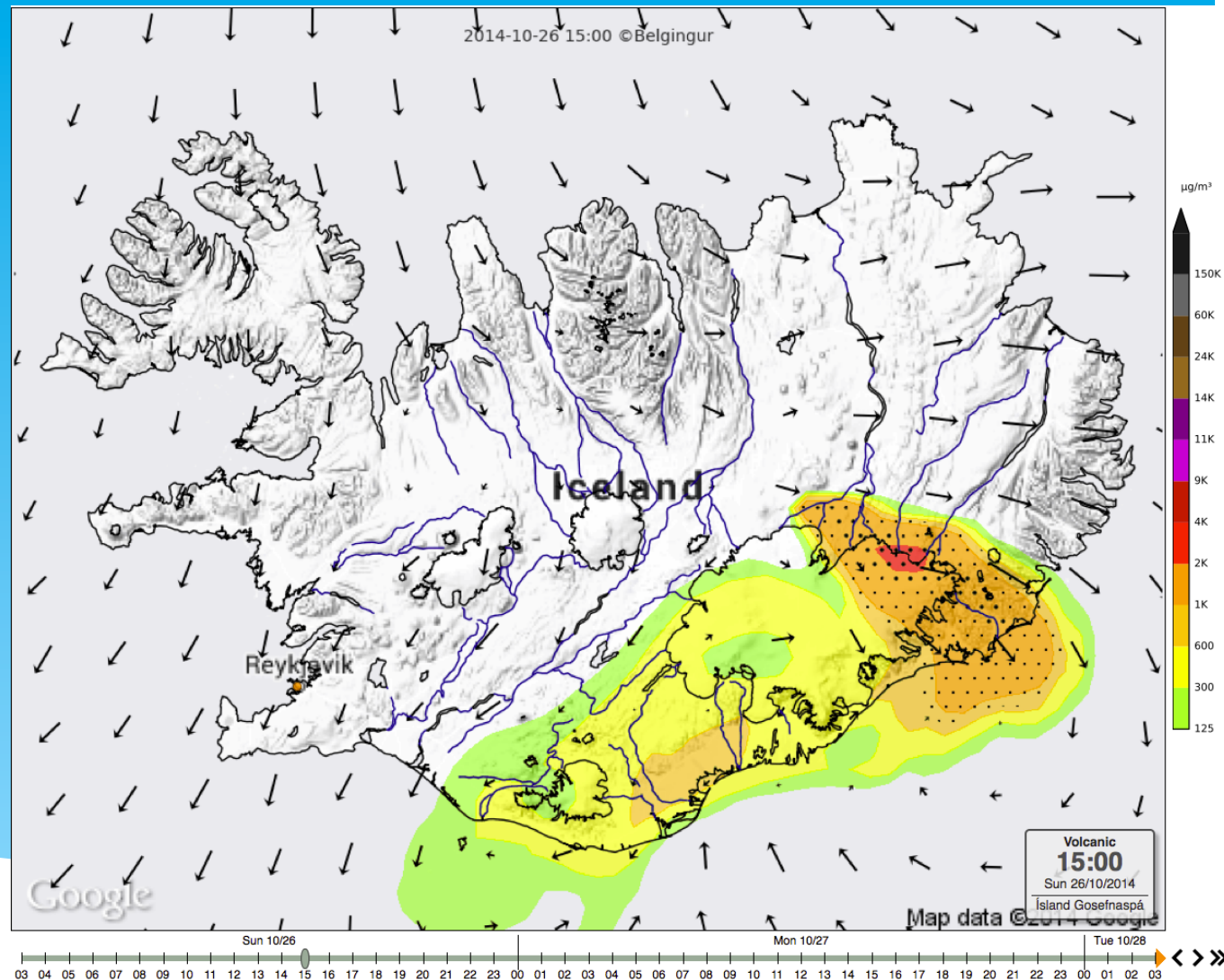
Loftgæði



SO₂ forecasts

SO₂ forecast for 15
UTC 2014-10-26

Strength of SO₂
around Höfn í
Hornafirði between
3000-7000 µg/m³



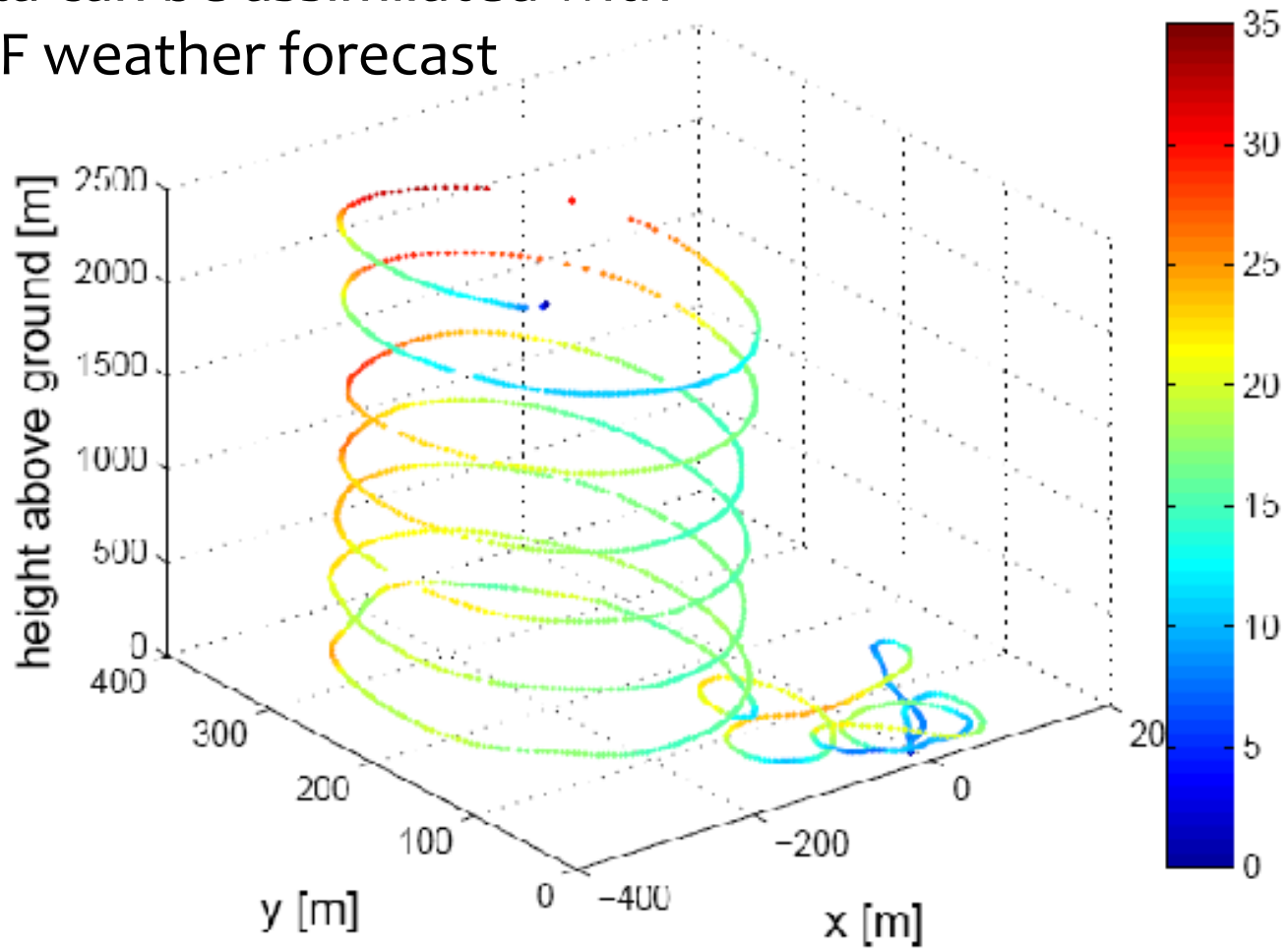
SUMO and WRF

The SUMO (Small Unmanned Meteorological Observer) can measure winds, humidity, pressure, and temperature in a vertical profile up 4km height



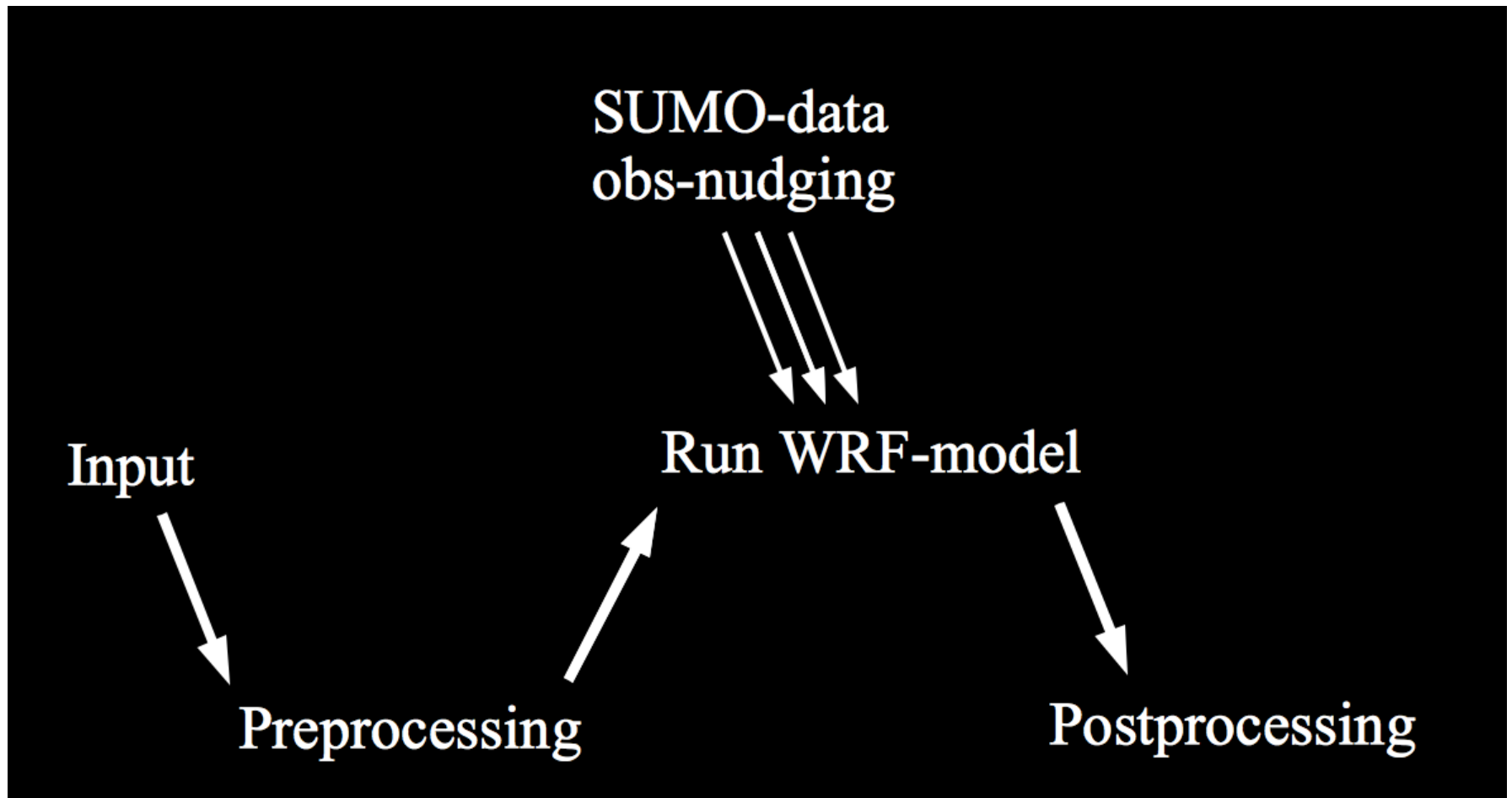
SUMO and WRF

This data can be assimilated with the WRF weather forecast



SUMO and WRF

The SUMO-data is incorporated into the WRF-simulation, via obs-nudging



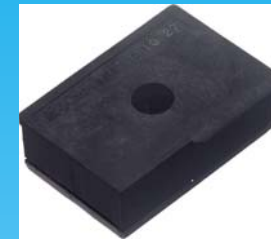
Additional sensors

The SUMO has been equipped with an optical dust sensor

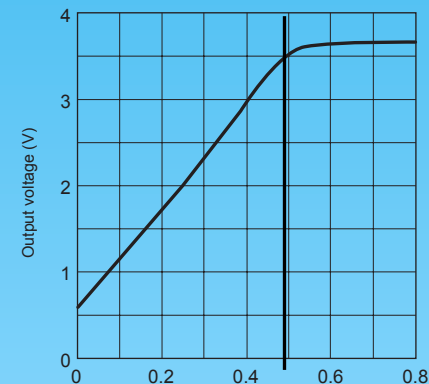
Compact Optical Dust Sensor

GP2Y1010AU0F is a dust sensor by optical sensing system:

- An infrared emitting diode (IRED) and an phototransistor are diagonally arranged into the device
- It detects the reflected light of dust in air
- Especially effective to detect very fine particle
- In addition it can distinguish smoke from house dust by pulse pattern of output voltage



Output Voltage vs. Dust Density



Saturation at about $500\mu\text{g}/\text{m}^3$

Preliminary results

The SUMO dust sensor has been tested in France and Iceland

