Meteorological Input Data: Ungrib and Metgrid

Lecture 3

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Lecture Objective and Learning Outcomes

Lecture objective

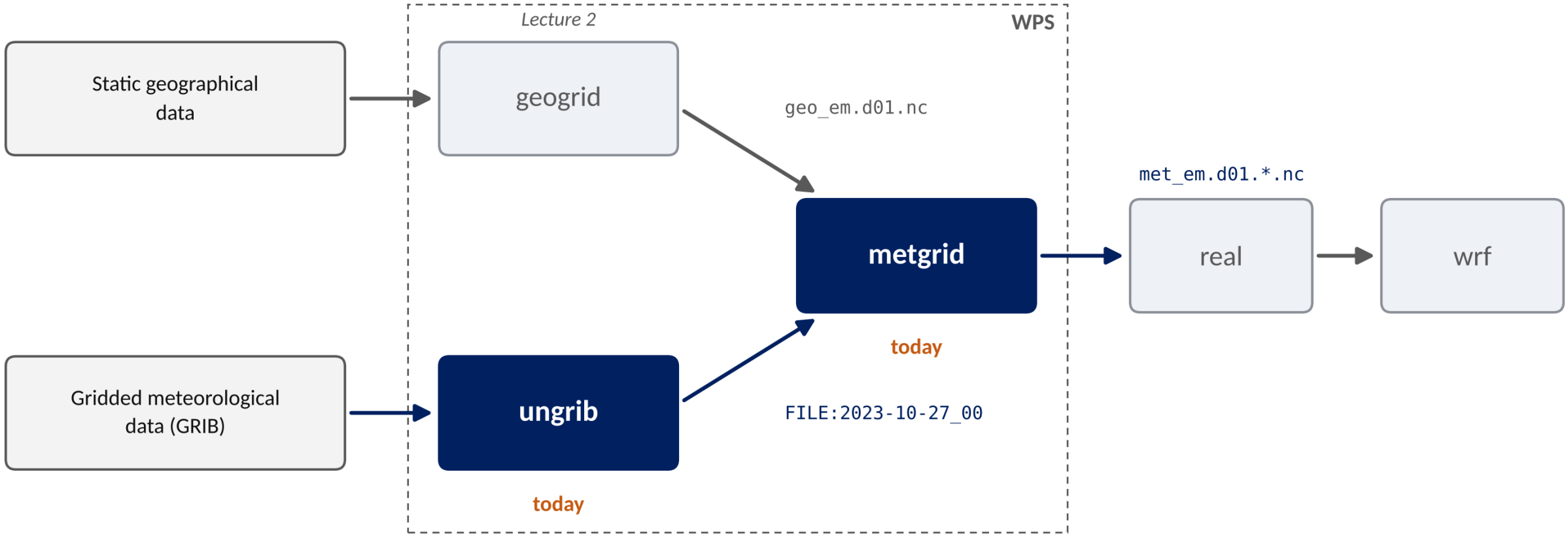
To explain how external meteorological data are prepared for WRF: the data sources, the GRIB format, and the ungrib and metgrid programs that produce the met_em files.

Learning outcomes

By the end of this lecture, students will be able to:

1. explain why a limited-area model needs initial and lateral boundary conditions;
2. compare GFS, ERA5 and FNL data and distinguish a forecast from an analysis or reanalysis;
3. describe the structure of a GRIB file and the role of the Vtable;
4. describe what ungrib and metgrid do and set their options in namelist.wps;
5. explain the staggered (Arakawa C) grid and check the met_em files for common problems.

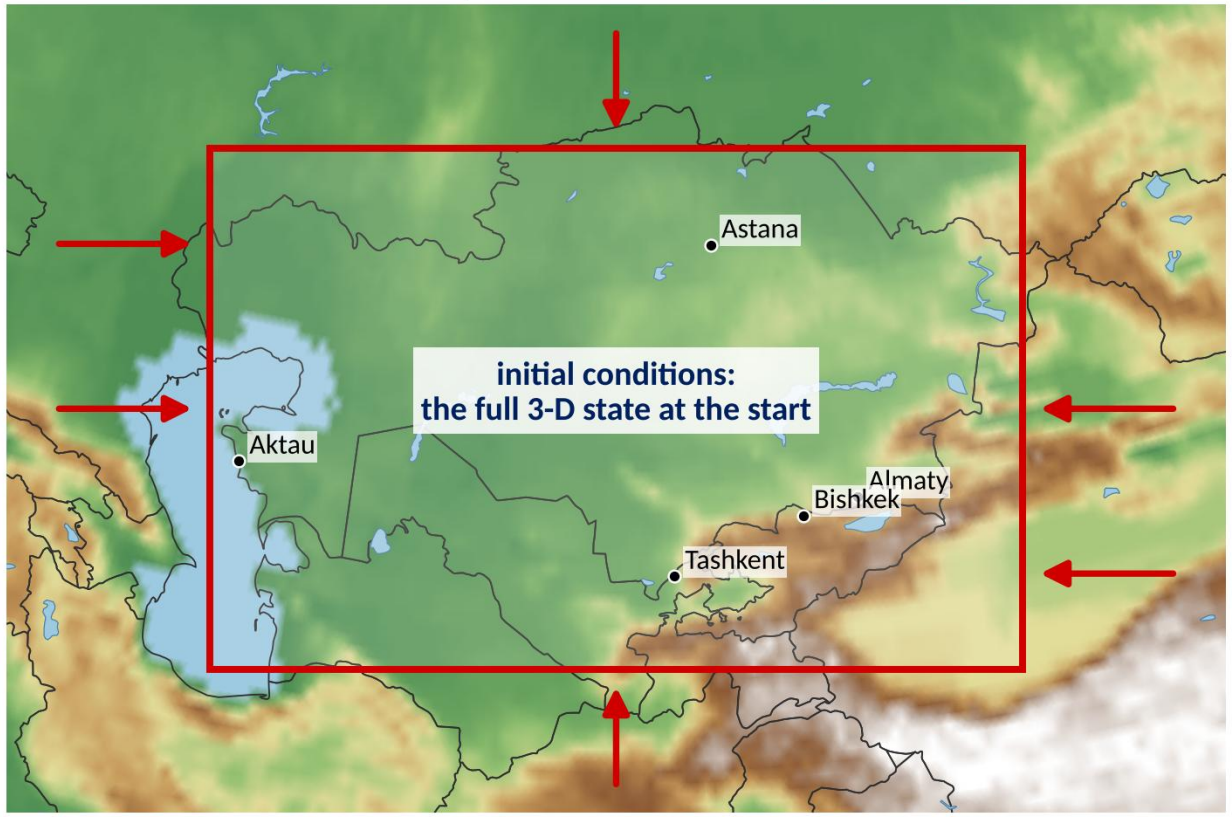
Where We Are in the Workflow



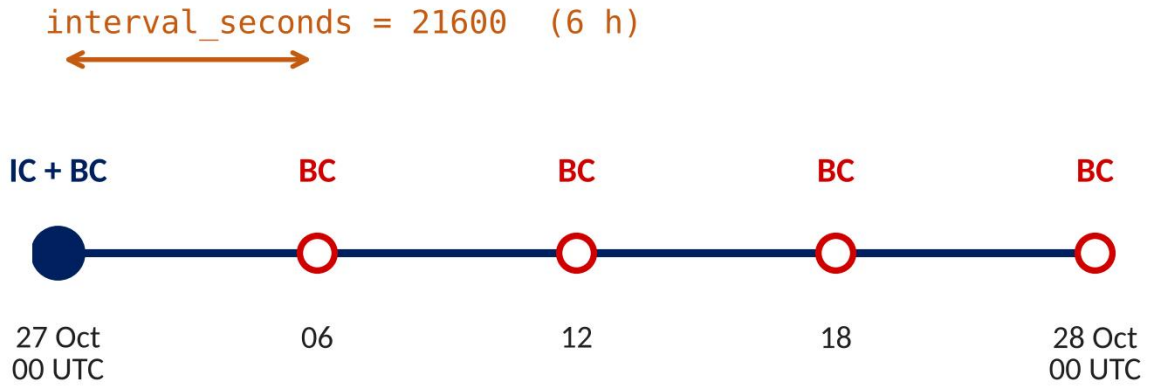
Today: from raw GRIB files to met_em files, ready for real.exe

Why WRF Needs External Meteorological Data

Lateral boundary conditions enter through the edges



One set of input fields for every boundary time



Between these times WRF interpolates the boundary values linearly in time

A limited-area model needs initial conditions (IC) and lateral boundary conditions (BC)

Sources of Meteorological Data

GFS (NCEP, USA)

- Global forecast
- 0.25° grid
- 4 runs per day: 00, 06, 12, 18 UTC
- Use: real-time forecasting

ERA5 (ECMWF)

- Global reanalysis
- 0.25° grid (about 31 km)
- Hourly fields, from 1940
- Use: past events, climate studies

FNL (NCEP, USA)

- Operational global analysis
- 0.25° grid
- Every 6 hours
- Use: case studies

- Forecast: what the model predicts for the future
- Analysis and reanalysis: the best estimate of the real atmosphere, combining a model with observations

Example from Research: Input Data for Almaty

Meteorological input

NCEP Climate Forecast System v2 (CFSv2) reanalysis: 1° grid, every 6 hours

From 1° to 1 km

Three nested domains: 9 km → 3 km → 1 km

Nudging

The 9-km domain is nudged towards the reanalysis (coefficient 0.0003 s^{-1})

Periods and output

January and July 2023; WRF output saved every hour

- Chemistry (CHIMERE) boundary conditions: climatology from the LMDZ-INCA global model

Source: Tursumbayeva et al. (2026), Meteorological Applications, 33, e70183

The GRIB Format

GRIB = GRIdded Binary

- A standard of the World Meteorological Organization
- Two editions: GRIB1 and GRIB2
- A file is a sequence of messages
- One message = one 2-D field: one variable, one level, one time
- Packed binary data: compact, but not readable as text

```
$ wgrib2 gfs.t00z.pgrb2.0p25.f000

…:d=2023102700:PRMSL:mean sea level:anl:
…
…:d=2023102700:HGT:850 mb:anl:
…:d=2023102700:TMP:850 mb:anl:
…:d=2023102700:RH:850 mb:anl:
…:d=2023102700:UGRD:850 mb:anl:
…:d=2023102700:VGRD:850 mb:anl:
…
…:d=2023102700:TMP:2 m above ground:anl:
…
```

Ungrib: From GRIB to Intermediate Files

Input: GRIB2 files (e.g. GFS 0.25°)

- gfs.t00z.pgrb2.0p25.f000
- gfs.t00z.pgrb2.0p25.f006
- gfs.t00z.pgrb2.0p25.f012
- gfs.t00z.pgrb2.0p25.f018

packed binary records, hundreds of fields per file

dates and time interval

namelist.wps

ungrib.exe

Vtable.GFS: which fields to extract

Param	Level	Name	Units	Description
11	100	TT	K	Temperature
33	100	UU	m s-1	U wind
34	100	VV	m s-1	V wind
52	100	RH	%	Relative humidity
7	100	HGT	m	Height
1	1	PSFC	Pa	Surface pressure

Output: intermediate files, one per time

- FILE:2023-10-27_00
- FILE:2023-10-27_06
- FILE:2023-10-27_12
- FILE:2023-10-27_18

only the fields WRF needs, still on the original lat–lon grid

Running Ungrib

```
namelist.wps
&share
 start_date = '2023-10-27_00:00:00',
 end_date   = '2023-10-28_00:00:00',
 interval_seconds = 21600,
/
&ungrib
 out_format = 'WPS',
 prefix     = 'FILE',
/
```

```
# 1. link the GRIB files
./link_grib.csh /data/gfs/gfs.t00z.*

# 2. link the Vtable for this data source
ln -sf ungrib/Variable_Tables/Vtable.GFS Vtable

# 3. run
./ungrib.exe

!  Successful completion of ungrib.  !
```

- interval_seconds: the time between two input files (21600 s = 6 h)
- The Vtable must match the data source: Vtable.GFS for GFS, a different table for ECMWF data

Which Fields Does WRF Need?

3-D fields on pressure levels

- Temperature (TT)
- Wind components (UU, VV)
- Relative humidity (RH)
- Geopotential height (GHT)

Surface and soil fields

- Surface and sea-level pressure (PSFC, PMSL)
- 2-m temperature and humidity, 10-m wind
- Skin temperature / SST (SKINTEMP)
- Soil temperature and moisture in layers (ST, SM)
- Land–sea mask, snow (LANDSEA, SNOW)

Metgrid: Horizontal Interpolation

from geogrid: the model grid

`geo_em.d01.nc`

from ungrib: meteorological fields

`FILE:2023-10-27_00`

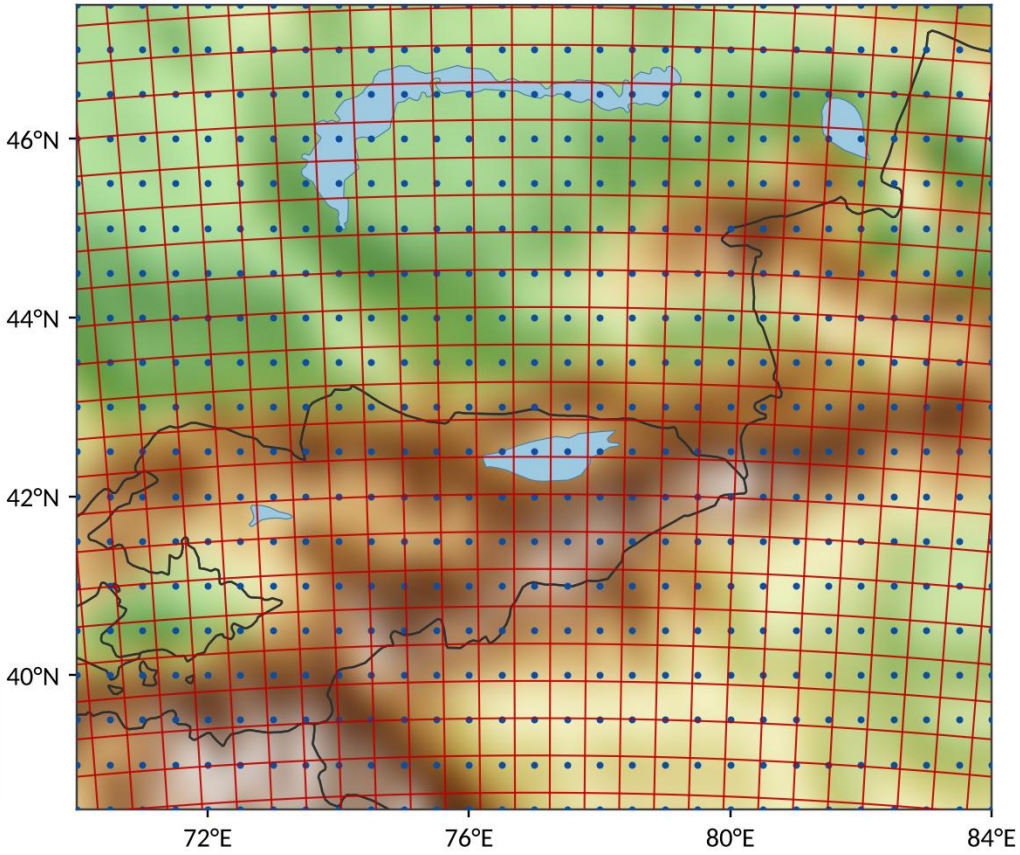
metgrid.exe

horizontal interpolation
(rules in METGRID.TBL)

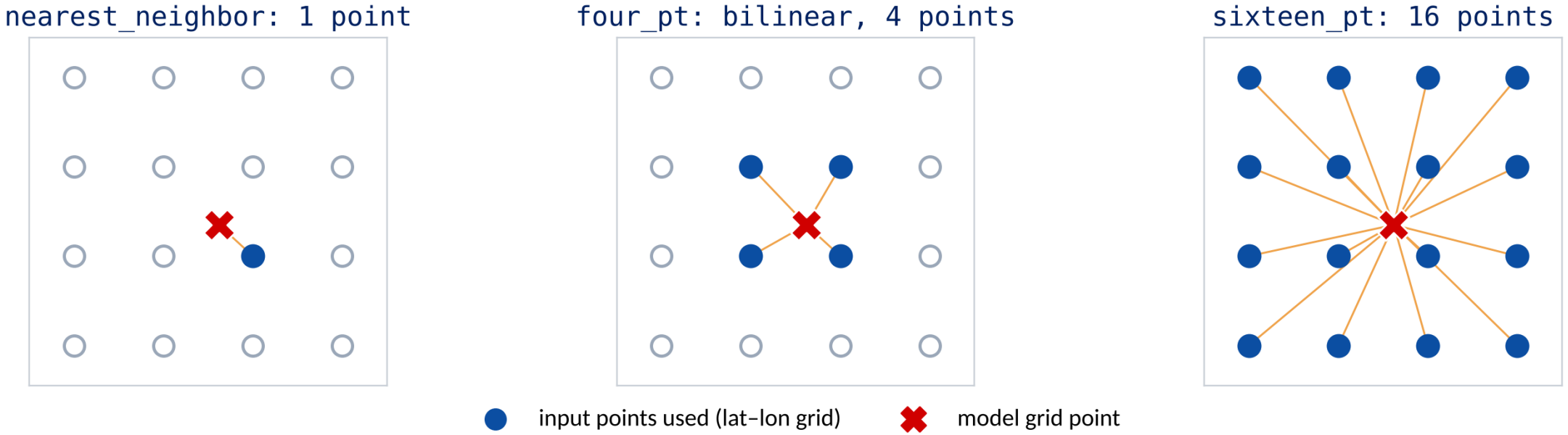
`met_em.d01.2023-10-27_00:00:00.nc`

one NetCDF file per time and per domain

Input points on a regular lat–lon grid (blue)
are interpolated to the model grid (red)



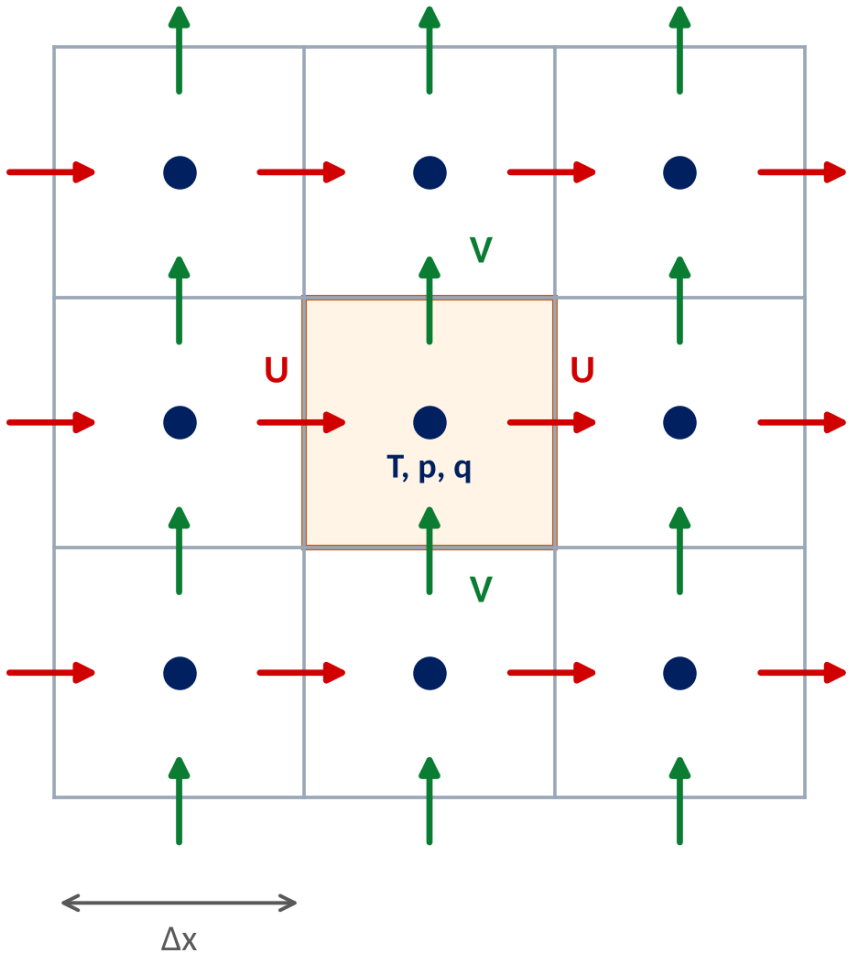
Interpolation Methods




```
METGRID.TBL (example)
name = TT
 mandatory = yes
 interp_option = sixteen_pt+four_pt+average_4pt
```

- Methods are tried in the given order until one can be applied
- Masked fields (SST, soil): land points use only land data, water points only water data

The Staggered Grid (Arakawa C)



Different variables live at different places in a grid cell

- Mass points (cell centre): T, p, q
- U points: west and east faces
- V points: south and north faces
- One more U point than mass points in each row
  - west_east = 226, west_east_stag = 227
  - south_north = 145, south_north_stag = 146

Running Metgrid

```
namelist.wps
&metgrid
 fg_name = 'FILE',
 io_form_metgrid = 2,
/

# run
./metgrid.exe

!  Successful completion of metgrid.  !
```

```
Output: one file per time and per domain

met_em.d01.2023-10-27_00:00:00.nc
met_em.d01.2023-10-27_06:00:00.nc
met_em.d01.2023-10-27_12:00:00.nc
met_em.d01.2023-10-27_18:00:00.nc
met_em.d01.2023-10-28_00:00:00.nc
```

- fg_name: the same prefix that was used in ungrib
- io_form_metgrid = 2: write the output in NetCDF format

Checking the met_em Files

```
$ ncdump -h met_em.d01.2023-10-27_00:00:00.nc

dimensions:
    Time = UNLIMITED ; // (1 currently)
    west_east = 226 ;
    south_north = 145 ;
    west_east_stag = 227 ;
    south_north_stag = 146 ;
    num_metgrid_levels = 34 ;
    num_st_layers = 4 ;
    num_sm_layers = 4 ;
```

Checklist

- Is there a file for every time?
- Do the grid dimensions match the domain (e_we, e_sn)?
- num_metgrid_levels: needed later in namelist.input
- Are the soil fields present?
- Do the fields look reasonable on a map?

Common Problems

Wrong Vtable

Ungrib runs, but fields are missing in the FILE:* files

Dates do not match the data

Ungrib stops: data for the requested time were not found

Data do not cover the domain or the period

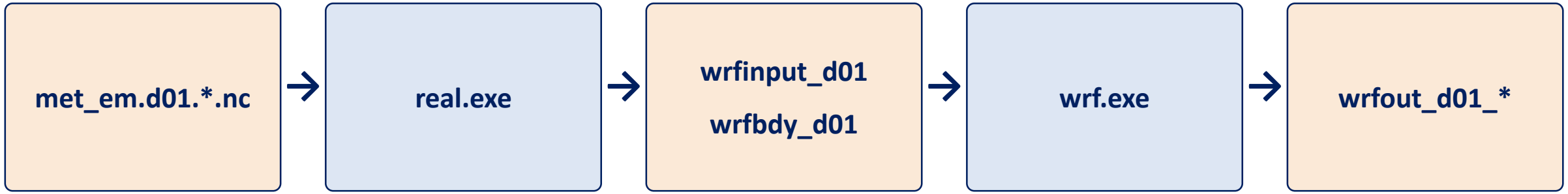
Missing values appear in the met_em files

Soil or surface fields are missing

WPS finishes, but real.exe fails later

Read the log files and check the output of each step before starting the next one

From met_em to the Model



- real.exe: vertical interpolation from pressure levels to the model levels
- wrfinput_d01: initial conditions; wrfbdy_d01: lateral boundary conditions
- wrf.exe: the simulation itself; the output is written to the wrfout files
- In namelist.input: num_metgrid_levels = 34, num_metgrid_soil_levels = 4

Summary

Key points

- A limited-area model needs initial and lateral boundary conditions
- Ungrib extracts the necessary fields from GRIB files using a Vtable
- Metgrid interpolates them horizontally onto the model grid, including the staggered U and V points
- The result: met_em files in NetCDF format
- Always check the output before running the model

Next lecture

The NetCDF format: dimensions, variables and attributes

Reading WRF files with Python

Thank you for your attention!

Self-Check Questions

1. Why does WRF need external meteorological data?
2. How does a forecast differ from an analysis or a reanalysis? Which dataset would you use for a past event?
3. What does one GRIB message contain?
4. What is a Vtable, and what happens if the wrong one is used?
5. Where are T, U and V located in an Arakawa C grid cell, and why is west_east_stag larger by one?
6. What should be checked in the met_em files before running real.exe?

References

1. Skamarock, W. C., et al. (2019). A Description of the Advanced Research WRF Model Version 4. NCAR Technical Note NCAR/TN-556+STR. https://doi.org/10.5065/1dfh-6p97
2. Tursumbayeva, M., Ciarelli, G., Di Antonio, L., Bettineschi, M., Kissebayev, D., & Baimatova, N. (2026). Modelling the Black Carbon Variability and Dynamics in Almaty, Kazakhstan, During Winter and Summer Seasons. Meteorological Applications, 33, e70183. https://doi.org/10.1002/met.70183
3. Saha, S., et al. (2014). The NCEP Climate Forecast System Version 2. Journal of Climate, 27(6), 2185–2208. https://doi.org/10.1175/JCLI-D-12-00823.1
4. NCAR Mesoscale and Microscale Meteorology Laboratory. WRF-ARW Version 4 Modeling System User's Guide. https://www2.mmm.ucar.edu/wrf/users/ (Chapter 3: WRF Preprocessing System)
5. Hersbach, H., et al. (2020). The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146(730), 1999–2049. https://doi.org/10.1002/qj.3803
6. National Centers for Environmental Prediction (2015). NCEP GDAS/FNL 0.25 Degree Global Tropospheric Analyses and Forecast Grids. NCAR Research Data Archive, dataset ds083.3.
7. World Meteorological Organization. Manual on Codes (WMO-No. 306), Volume I.2: International Codes – GRIB.
8. Arakawa, A., & Lamb, V. R. (1977). Computational design of the basic dynamical processes of the UCLA general circulation model. Methods in Computational Physics, 17, 173–265.
9. Figure data: NOAA National Geophysical Data Center, ETOPO global relief model; Natural Earth, naturalearthdata.com.