

The Developmental Testbed Center

WRFv3.5 Noah-MP LSM Sensitivity Test Plan

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1. Introduction

The Developmental Testbed Center (DTC) will test and evaluate two configurations of the Weather Research and Forecasting (WRF) model with the Advanced Research WRF (ARW) core (Skamarock et al. 2008) for the Air Force Weather Agency (AFWA). One configuration is based on AFWA's Operational Configuration (OC), while the second configuration substitutes AFWA's current operational land surface scheme (Noah LSM) with the Noah scheme with multi-parameterization options (Noah-MP LSM; Niu et al. 2011). Both configurations will use WRF version 3.5, initialized with output from AFWA's Land Information System (LIS) version 2.7.1. A functionally similar environment to AFWA operations will be utilized where each configuration will be initialized with a 6-hour "warm start" spin-up, including data assimilation.

The end-to-end forecast system will employ the WRF Preprocessing System (WPS), WRF Data Assimilation (WRFDA) system, WRF, and Unified Post Processor (UPP). Post-processed forecasts will be verified using the Model Evaluation Tools (MET). The versions of the packages used will correspond to the current public releases available at the time testing commences and any known, relevant bug fixes to these versions will also be incorporated.

2. Goals

The inter-comparison of the two configurations to be tested during this performance period (AOP2013) will allow for an assessment of the impact due to the different LSM options in WRF. An inter-comparison of the WRFv3.5 with Noah LSM configuration and the previously tested (AOP2012) WRFv3.4 with Noah LSM configuration will also allow for an assessment of the impact due to the updated versions of the system components (WPS, WRFDA, WRF). Forecast verification statistics will be computed for each of the configurations, and the analysis will be based on the objective statistics of the model output. A secondary goal of this test and evaluation will be to designate new a DTC Reference Configuration and widely publish the output and results for the benefit of the entire WRF community.

3. Experiment Design

The end-to-end forecast system is composed of the WPS, WRFDA, WRF-ARW model, UPP, MET, graphics generation, data archival, and dissemination of data and results.

3.1 Codes to be Employed

For the results to be most relevant to the user community, testing will be conducted utilizing officially released code when possible. The baseline codes utilized will include WPS (v3.5), WRFDA (v3.5), WRF (v3.5), UPP (v2.1), and MET (v4.1). Relevant bug fixes to all software packages will be incorporated if any are known by the final software acquisition deadline.

The workflow manager, Rocoto, developed by the National Oceanic and Atmospheric Administration (NOAA) Earth Systems Research Laboratory, will be utilized to manage the execution of the end-to-end system. Rocoto controls the system execution, starting tasks as soon as their dependencies have been met, monitoring task execution, and re-starting tasks when needed.

3.2 Domain Configurations

A 15-km contiguous U.S. (CONUS) grid will be employed in this test. The domain (Figure 1) was selected such that it covers complex terrain, plains and coastal regions spanning from the Gulf of Mexico, north, to Central Canada in order to capture diverse regional effects for worldwide comparability. The domain is 403 x 302 gridpoints, for a total of 121,706 gridpoints. The Lambert-Conformal map projection will be used and the configurations will use 56 vertical levels (57 sigma entries), with a pressure top of 10 hPa.

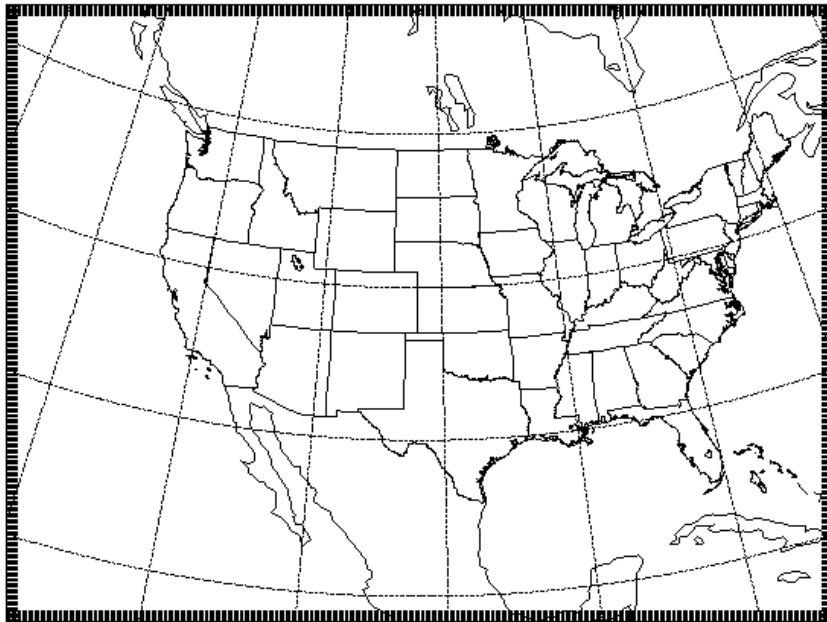


Figure 1. Map showing the boundary of the WRF-ARW computational domain.

Verification results will be computed for selected spatial aggregations, including the entire CONUS, CONUS-West, CONUS-East and 14 regional domains shown in Fig. 2.

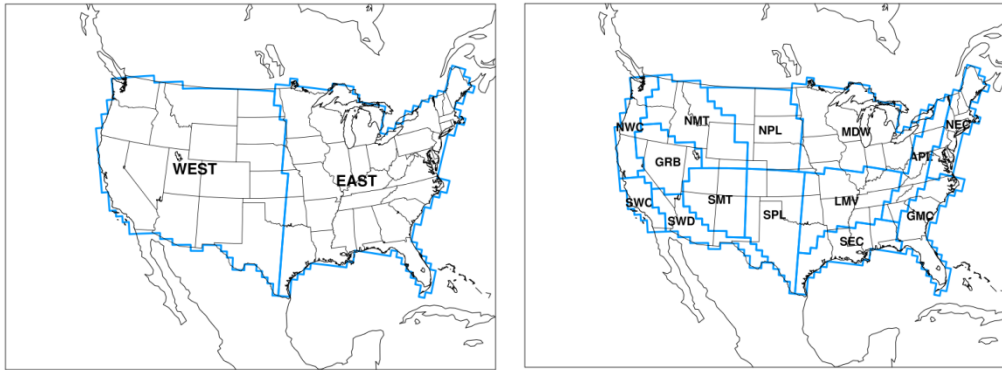


Figure 2. Map showing the locations of the CONUS-West, CONUS-East and 14 regional verification domains. The outermost outline of the regional domains depict the CONUS verification domain.

3.3 Initial and Boundary Conditions

Initial conditions (ICs) and lateral boundary conditions (LBCs) will be derived from the 0.5° x 0.5° Global Forecast System (GFS). Output from AFWA’s LIS running version 2.7.1 of the Noah land surface model, will be utilized for the lower boundary conditions (LoBCs). In addition, a daily, real-time sea surface temperature product from Fleet Numerical Meteorology and Oceanography Center (FNMOC) will be used to initialize the sea surface temperature (SST) field for the forecasts.

The time-invariant component of the lower boundary conditions (topography, soil and vegetation type etc.), using United States Geological Survey (USGS) input data, will be generated through the *geogrid* program of WPS. The *avg_tsfc* program of WPS will also be used to compute the mean surface air temperature in order to provide improved water temperature initialization for lakes and smaller bodies of water in the domain that are further away from an ocean.

A 6-hour “warm start” spin-up procedure (Fig. 3) will precede each forecast. Data assimilation using WRFDA will be conducted at the beginning and the end of the 6-hour window using observation data files provided by AFWA. At the beginning of the data assimilation window, the GFS derived initial conditions will be used as the model background, and at the end of the window, the 6-hour WRF forecast initialized by the WRFDA analysis will be used. Seasonal, domain-specific model error statistics (BE) files will be used in WRFDA. After each WRFDA run, the LBCs derived from GFS will be updated and used in the subsequent forecasts.

BE files for WRFDA were created in AOP2012 from cold-start WRF forecasts conducted on the 15-km grid twice daily for 15 days each season. This resulted in 30 forecasts per season, or 120 total forecasts (24-h forecasts, in 12-h increments). These forecasts were used as input into the *gen_be* utility in WRFDA to generate the seasonal BE files that will be used for testing again in AOP2013.

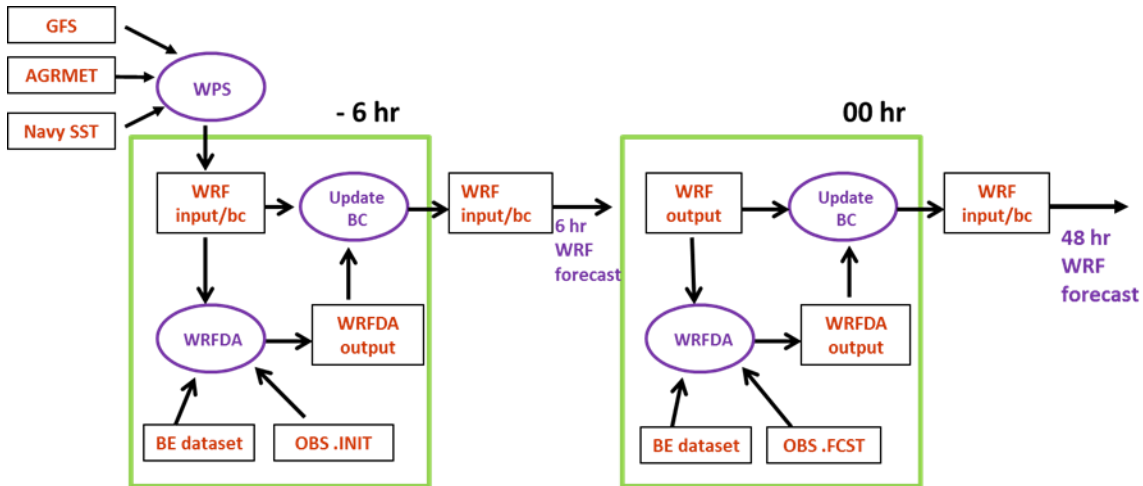


Figure 3. Schematic of workflow process to be used for warm start initialization with data assimilation. BC=Boundary Conditions; BE=Background Error.

3.4 Forecast Periods

Forecasts will be initialized every 36 hours from 1 July 2011 through 29 June 2012 (Appendix B). The forecasts will be run out to 48 hours with output files generated every 3 hours. The initialization times will include 00 and 12 UTC for a total of 244 cases. These were the same cases for which the AOP2012 testing and evaluation for AFWA was conducted.

3.5 Physics Suites

A sample namelist is given in Appendix A. The physics suite configurations are described in Table 1 below.

Table 1. Physics suite combination for the AFWA OC.

	Current AFWA OC	Noah-MP configuration
Microphysics	WRF Single-Moment 5 scheme	WRF Single-Moment 5 scheme
Radiation SW and LW	Dudhia/RRTM schemes	Dudhia/RRTM schemes
Surface Layer	Monin-Obukhov similarity theory	Monin-Obukhov similarity theory
Land-Surface Model	Noah	Noah-MP
Planetary Boundary Layer	Yonsei University scheme	Yonsei University scheme
Convection	Kain-Fritsch scheme	Kain-Fritsch scheme

3.6 Other Aspects of Model Configuration

A long timestep of 90 s and an acoustic step of 4 will be used. Calls to the boundary layer and microphysics will be done every time step, whereas calls to cumulus will be done every 5 minutes and radiation will be done every 30 minutes.

The ARW solver offers a number of run-time options for the numerics, as well as various filter and damping options (Skamarock et al. 2008). The ARW will be configured to use the following numeric options: 3rd-order Runge-Kutta time integration, 5th-order horizontal momentum and scalar advection, and 3rd-order vertical momentum and scalar advection. In addition, the following filter/damping options will be utilized: three-dimensional divergence damping (coefficient 0.1), external mode filter (coefficient 0.01), off-center integration of vertical momentum and geopotential equations (coefficient 0.1), vertical-velocity damping, and a 5-km-deep w-Rayleigh damping layer at the top of the domain (coefficient 0.05). Positive-definite moisture advection will also be turned on.

3.7 Post-processing

The *unipost* program within UPP will be used to destagger the forecasts, to generate derived meteorological variables, including mean sea level pressure, and to vertically interpolate fields to isobaric levels. The post-processed files will include two- and three-dimensional fields on constant pressure levels, both of which are required by the plotting and verification programs. Three-dimensional post-processed fields on model native vertical coordinates will also be made available.

3.8 Model Verification

Objective model verification statistics will be generated using the MET package. MET is comprised of grid-to-point comparisons which are utilized to compare gridded surface and upper-air model data to point observations, as well as grid-to-grid comparisons which are utilized to verify quantitative precipitation forecasts (QPF).

Forecasts for mean-sea level pressure and surface and upper-air temperature, height, dewpoint, and wind will be interpolated to the location of the observations (METARs, RAOBS, and buoy data) using MET. The NCEP North American Data Assimilation System (NDAS) prepbufr files will be used as the observational dataset. Bias and bias-corrected root-mean-square-error (BCRMSE) will be computed for temperature, dewpoint, and winds, computed separately for each observational type. For the precipitation verification, a grid-to-grid comparison will be made in which the precipitation analyses will first be interpolated to the 15-km model integration domain and then compared to the forecast. Accumulation periods will be 3 h and 24 h. The observational dataset will be the NCEP Stage II analysis for the 3-h and 24-h (valid at 12 UTC) accumulations. Traditional verification metrics computed will include the frequency bias and the Gilbert Skill Score (GSS).

Verification statistics will be stratified by lead time, vertical level, and regional area for 00 UTC and 12 UTC initialization hours combined. For the surface fields, forecasts will also be stratified by initialization hour (00 and 12 UTC). The regional areas for aggregation of statistics for the surface and upper-air fields will include the CONUS, CONUS-West, CONUS-East and 14 regional sub-domains (shown in Fig. 2).

Since every forecast will be run for both configurations of the model, the presentation of the results will take advantage of the pair-wise nature of the test. With this methodology, differences between the verification statistics for each individual initialization and lead time of two configurations at a time will be computed. In addition to the two configurations to be tested during this period of performance, the AFWA OC configuration based on WRFv3.4 with Noah LSM was tested in AOP2012. Therefore, inter-comparisons will be performed for the following pairs:

- WRFDAv3.5 + WRFv3.5 w/ Noah **versus** WRFDAv3.5 + WRFv3.5 w/ Noah-MP
- WRFDAv3.5 + WRFv3.5 w/ Noah **versus** WRFDAv3.4 + WRFv3.4 w/ Noah

For surface and upper-air, both the individual and pair-wise verification statistics will be accompanied by confidence intervals (CIs) computed from standard error estimates using a correction for autocorrelation. The CIs will be computed on the median values of the stratified results for the surface and upper-air statistics using parametric tests. For the precipitation statistics, a bootstrapping method will be used. The CIs on the pair-wise differences between statistics for two configurations will assist in determining whether the differences are statistically significant.

3.9 Graphics Generation and Display

Graphics will be generated using NCAR Command Language (NCL) and ultimately displayed on the DTC web site. The suite of images generated for each of the stand-alone configurations and the differences between the two pairs of configurations used for inter-comparison will be comprised of:

- 2-m temperature with 10-m wind vectors
- 2-m dewpoint temperature with 10-m wind vectors
- 10-m wind speed and vectors
- 3-h accumulated total precipitation with MSLP and 1000-500 hPa thickness
- precipitation type
- simulated radar composite reflectivity
- snow water equivalent
- convective available potential energy
- convective inhibition
- precipitable water
- 850 hPa temperature with geopotential height and wind vectors
- 850 hPa wind speed with geopotential height and vectors
- 850 hPa relative humidity
- 850-500 hPa mean relative humidity and 700 hPa wind vectors
- 700 hPa vertical velocity with geopotential height
- 500 hPa absolute vorticity with geopotential height
- 250 hPa wind vectors with geopotential height

Finally, Skew-T soundings showing both configurations for each of the inter-comparison pairs side-by-side from 14 stations (one from each sub-domain) will be created for the following sites:

- Quillayute, WA
- Vandenberg AFB, CA
- Desert Rock, NV
- Spokane, WA
- Denver, CO
- Tucson, AZ
- Rapid City, SD
- Amarillo, TX
- Davenport, IA
- Springfield, MO
- Jackson, MS
- Blacksburg, VA
- Albany, NY
- Charleston, SC

4. *Data Archival and Dissemination of Results*

Input and output data files from several stages of the end-to-end system will be archived to the NCAR High Performance Storage System (HPSS). Access to the data sets can be requested by contacting a DTC staff member. The results will be summarized in a report and publicized on the DTC website.

5. *Computer Resources*

- Processing resources:
All forecasts and calculations will be computed on the NCAR supercomputer
- Storage resources:
All archival will be done on the NCAR HPSS
- Web resources:
Model forecast and verification graphics will be accessible through a web interface available on the DTC web site

6. *Deliverables*

The NCAR HPSS will be used to archive the files produced by the forecast system. The following files will be stored:

- GFS, AFWA LIS analysis grids using Noah v2.7.1, and SST files used for initial and boundary conditions

- Seasonal background error covariance files and Special Sensor Microwave Imager (SSM/I) and Global Telecommunication System (GTS) observation files for the 6-hour warm start and 48-hour forecast
- Datasets used for forecast verification (NDAS Prepbufr and Stage II precipitation analyses)
- Static files produced by the **geogrid** component of WPS
- Final output of WPS
- WRFDA analysis files, updated lateral boundary files, and WRFDA diagnostic files of the cost function, gradient function, and statistics of the analysis increments.
- Input and boundary condition files produced by **real**
- History files produced by WRF
- Output of the **unipost** component of the UPP
- Output of MET
- Images produced by NCL

Additionally, all source codes and executables used will be stored. These files will be made available to interested parties for further studies upon request.

The DTC will produce a report outlining the results and conclusions from this test. A website for viewing the verification results will be made available to the community-at-large upon completion of the test.

7. References

Niu, G.-Y., et al. (2011), The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements. *J. Geophys. Res.*, 116, D12109, doi: 10.1029/2010JD015139.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang and J. G. Powers, 2008: A Description of the Advanced Research WRF Version 3, NCAR Tech Note, NCAR/TN-475+STR, 113 pp.

Appendix A: Subset of the *namelist.input*

&wrfv4

```
thin_conv      = .TRUE.,
use_synopobs   = .TRUE.,
use_shipsobs   = .TRUE.,
use_metarobs   = .TRUE.,
use_soundobs   = .TRUE.,
use_mtgirsobs  = .TRUE.,
use_tamdarobs  = .TRUE.,
use_pilotobs   = .TRUE.,
use_airepobs   = .TRUE.,
use_geoamvobs  = .TRUE.,
use_polaramvobs = .TRUE.,
use_buoyobs    = .TRUE.,
use_profilerobs = .TRUE.,
use_satemobs   = .TRUE.,
use_gpspwobs   = .TRUE.,
use_gpsrefobs  = .TRUE.,
top_km_gpsro  = 30.0,
bot_km_gpsro   = 0.0,
use_ssmiretrievalobs = .TRUE.,
use_qscatobs   = .TRUE.,
```

&wrfvar6

```
max_ext_its    = 2,
ntmax          = 200,
nsave          = 4,
write_interval = 5,
eps            = 1.E-02,
precondition_cg = .FALSE.,
precondition_factor = 1.0,
use_lanczos    = .FALSE.,
orthonorm_gradient = .FALSE.,
```

&time_control

```
run_hours      = 48,
interval_seconds = 10800,
history_interval = 180,
frames_per_outfile = 1,
restart        = .false.,
io_form_history = 2,
input_outname  = "wrfinput_d<domain>_<date>",
/
```

&domains

```
time_step      = 90,
time_step_fract_num = 0,
time_step_fract_den = 1,
max_dom        = 1,
e_we           = 403,
e_sn           = 302,
e_vert         = 57,
num_metgrid_levels = 27,
num_metgrid_soil_levels = 4,
dx             = 15000,
```

```

dy = 15000,
p_top_requested = 1000,
interp_type = 1,
lowest_lvl_from_sfc = .false.,
lagrange_order = 1,
force_sfc_in_vinterp = 6,
zap_close_levels = 500,
adjust_heights = .false.,
eta_levels = 1.000, 0.997, 0.992, 0.985, 0.978, 0.969, 0.960, 0.950,
           0.938, 0.925, 0.910, 0.894, 0.876, 0.857, 0.835, 0.812,
           0.787, 0.760, 0.731, 0.700, 0.668, 0.635, 0.600, 0.565,
           0.530, 0.494, 0.458, 0.423, 0.388, 0.355, 0.323, 0.293,
           0.264, 0.237, 0.212, 0.188, 0.167, 0.147, 0.130, 0.114,
           0.099, 0.086, 0.074, 0.064, 0.054, 0.046, 0.039, 0.032,
           0.027, 0.022, 0.017, 0.013, 0.010, 0.007, 0.004, 0.002,
           0.000,

```

/

```

&physics
mp_phycis = 4,
ra_lw_physics = 1,
ra_sw_physics = 1,
radt = 30,
sf_sfclay_physics = 1,
sf_surface_physics = 2,
bl_pbl_physics = 1,
bldt = 0,
cu_physics = 1,
cudt = 5,
surface_input_source = 1,
num_soil_layers = 4,
num_land_cat = 28,
mp_zero_out = 2,
/

```

```

&noah_mp
dveg = 4,
opt_crs = 1,
opt_sfc = 1,
opt_btr = 2,
opt_run = 3,
opt_frz = 1,
opt_inf = 1,
opt_rad = 3,
opt_alb = 2,
opt_snf = 1,
opt_tbot = 2,
opt_stc = 1,
/

```

```

&dynamics
rk_ord = 3,
diff_6th_opt = 2,
diff_6th_factor = 0.10
w_damping = 1,
diff_opt = 1,

```

```

km_opt           = 4,
damp_opt         = 3,
zdamp           = 5000.,
dampcoef         = 0.05
khdif           = 0,
kvdif           = 0,
smdiv           = 0.1,
emdiv           = 0.01,
epssm           = 0.1,
time_step_sound = 0,
h_mom_adv_order = 5,
v_mom_adv_order = 3,
h_sca_adv_order = 5,
v_sca_adv_order = 3,
moist_adv_opt   = 1,
scalar_adv_opt  = 0,
chem._adv_opt   = 0,
tke_adv_opt     = 0,
/

&bdy_control
spec_bdy_width  = 5,
spec_zone       = 1,
relax_zone      = 4,
specified       = .true.,
/

```

Appendix B: Case list

00 UTC Initialization	12 UTC Initialization
July 2011: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31	July 2011: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29
August 2011: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30	August 2011: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31
September 2011: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29	September 2011: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30
October 2011: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29	October 2011: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30
November 2011: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28	November 2011: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29
December 2011: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31	December 2011: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29
January 2012: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30	January 2012: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31
February 2012: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29	February 2012: 3, 6, 9, 12, 15, 18, 21, 24, 27
March 2012: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30	March 2012: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31
April 2012: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29	April 2012: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30
May 2012: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29	May 2012: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30
June 2012: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28	June 2012: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29