WIND FORECASTS FOR ROCKET AND BALLOON LAUNCHES AT THE ESRANGE SPACE CENTER

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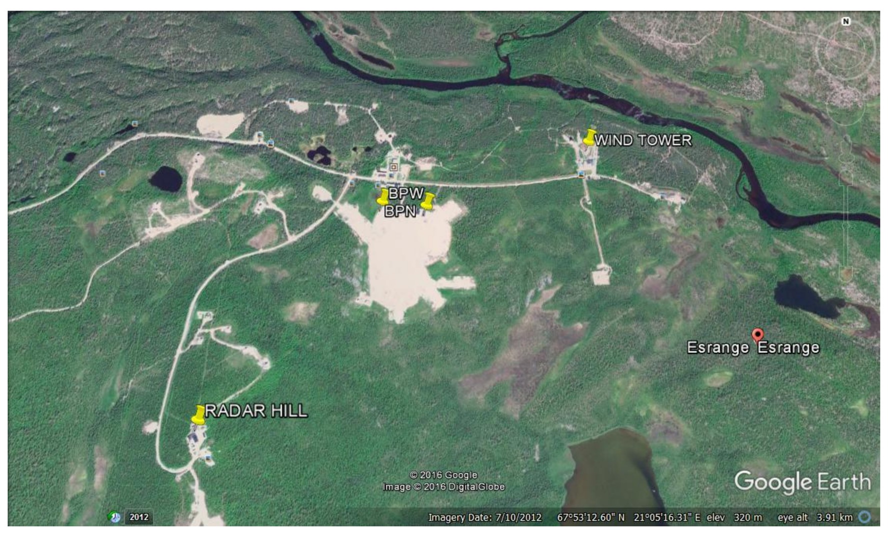
Introduction and Experimental Setup

- The Esrange Space Center (ESC) is located at ~67.88ºN and 21.05ºE in the Swedish Lapland, ~200 km north of the Arctic Circle. The ESC is just outside the city of Kiruna and has been extensively used to launch high-altitude rocket and balloons to study the dynamics of the upper-levels of the Earth's atmosphere.
- Weather conditions play a crucial role in the decision of whether a planned launch will actually take place. Four meteorological phenomena are particularly relevant for rocket operations (Kingwell et al., 1991):
  - **Lightning**: electrical surges can lead to a loss of control and even to the destruction of the rocket;
  - **Wind**: major issue in particular when the rocket is near the surface and its relative velocity is low;
  - **Turbulence**: can lead to unacceptable stresses on key components of the rocket;
  - **Temperature**: excessively high and low temperatures can cause damage to components of the rocket and affect the performance of ground crews and equipment.

  Out of those factors, the one that is found to be most relevant to launches at the ESC is the wind.
- The Weather Research and Forecasting (WRF; Skamarok et al., 2008) model version 3.7.1 is used to dynamically downscale 5-day forecasts by the Global Forecast System (GFS; Sun et al. 2010) for the ESC (Fonseca et al., 2018). The goals of this work are twofold:
  - Test different model configurations, in particular Planetary Boundary Layer (PBL) parameterization schemes, and find the one that gives the most skillful wind forecasts for use in future simulations;
  - Check whether the WRF wind forecasts can be used for go/no-go decisions for the two most commonly launched vehicles at the ESC.
- WRF is run in a four-nested configuration for 2 × 5-day periods in the summer, winter and transition seasons with the innermost grid at 1 km spatial resolution. A 5-day run with just two computational nodes (96 Central Processing Units) at the High Performance Computing Center North Abisko cluster takes less than 1.5 days, allowing the model forecasts to be available for the pre-flight meeting (2 days before a planned launch) and for the time when the final decision on whether to go ahead or postpone a launch is made (generally the day before a planned launch date) → **proposed methodology can be applied to real-time launch events**;
- In this work, three PBL schemes are tested: the nonlocal YSU, the local MYJ, and the hybrid local-nonlocal ACM2. The ACM2 scheme is found to generally give the best scores for all seasons and will therefore be used in future simulations.

WRF CONFIGURATION

Physics Options	Parameterization Scheme
Microphysics	Goddard (six-class) Cloud Microphysics Scheme
Radiation	Rapid Radiative Transfer Model for GCM Applications (RRTMG)
Surface Layer	Revised MM5 Monin-Obukhov Scheme
Land Surface	Noah Land Surface Model
Planetary Boundary Layer	Yonsei University (YSU; Hong et al., 2006) Mellor-Yamada-Janjić (MYJ; Janjić, 1990, 1994) Asymmetric Convective Model 2 (ACM2; Pleim, 2007a, 2007b)
Cumulus *(27 km and 9 km grids only)*	Betts-Miller-Janjić (BMJ) Scheme + Precipitating Convective Cloud (PCC) Scheme (Koh et al., 2016)
Sea Surface Temperature	GFS SSTs + simple skin temperature scheme (Zeng et al., 2005)



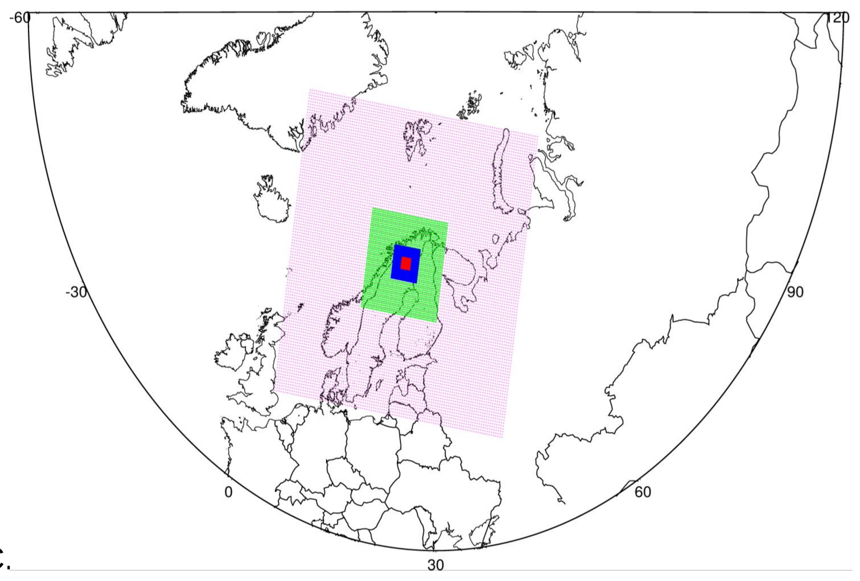
Aerial view (image taken from Google Earth) of the ESC. Weather observations are taken at four platforms:

WIND TOWER: horizontal wind (direction & speed) at ~10, 25, 45, 65, 85 and 100 m above ground level (AGL)

RADAR HILL: horizontal wind & temperature at ~40 m AGL

BALLOON PAD NORTH (BPN): horizontal wind at ~20 m AGL

BALLOON PAD WEST (BPW): horizontal wind (at ~3.5m AGL) and pressure, temperature and relative humidity (at ~3 m AGL)



PURPLE: 27 km grid

GREEN: 9 km grid

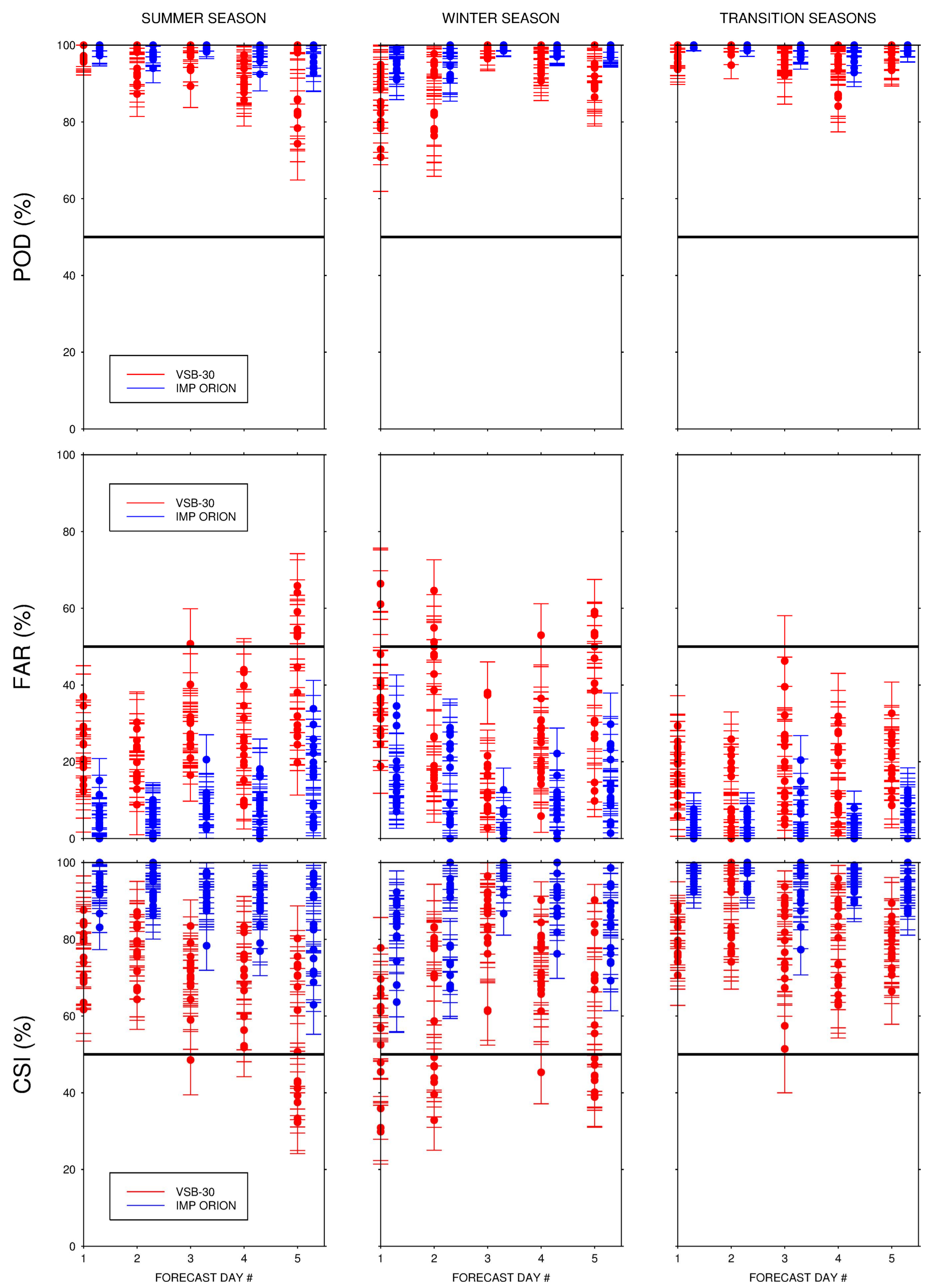
BLUE: 3 km grid

RED: 1 km grid

Launch Criteria for Sounding Rockets

- The potential use of the WRF forecasts for planned launches is qualitatively assessed using the Probability of Detection (POD), False Alarm Rate (FAR) and Critical Success Index (CSI) scores (Schaefer, 1990):
  - **POD**: fraction of actual events successfully predicted by the model;
  - **FAR**: fraction of model forecasts that turn out not to be correct;
  - **CSI**: ratio of number of correct forecasts to total number of forecasts that were either made or needed.

  The perfect scores are 100% for POD and CSI and 0% for FAR.
- The two most commonly launched vehicles at the ESC are sounding rockets Veículo de Sondagem Booster - 30 (VSB-30) and Improved Orion (IO). Regarding the launch requirements, for VSB-30 a maximum variation in the horizontal wind speed of 1.8 m s^{-1} and in the wind direction of 25º in the time window from the moment when the final launch settings are configured (typically six minutes before launch) to the actual launch time has to be accomplished. For IO, the requirements are 2.7 m s^{-1} for wind speed and 65º for wind direction (Martin Bysell, Swedish Space Corporation, *per. comm.*).
- Figures show the POD, FAR and CSI scores, computed using the 10-minute WRF and observed data, for each vehicle and forecast day for the two summer, winter and transition seasons' 5-day simulations. Launch criteria are applied separately at each platform with the 95% confidence intervals, estimated using bootstrapping based on 4000 bootstrap samples, shown as error bars. Higher scores for the IO rocket are consistent with the less restrictive criteria for the maximum wind speed and direction shifts for this vehicle.
- For all seasons and forecast days, POD scores are in excess of 60% for VSB-30 and 85% for IO meaning that **in about two-thirds of the time or more when there are favourable conditions for the launches, WRF gives a successful forecast**. The FARs are generally below 60% for VSB-30 and 45% for IO. CSIs are above 50% for all seasons for the IO rocket but for VSB-30 at times are as low as 20%. A further inspection of the figures also reveals that:
  - Overall the skill scores for the winter season are lower and show a larger spread. The two winter periods chosen are characterized by strong near-surface winds with the model, at this spatial resolution and with this configuration, failing to simulate well the observed temporal variability of the horizontal wind vector;
  - For the summer season there is a general deterioration of the scores with forecast time. This is expected as the GFS data, used to generate the initial/boundary conditions for WRF runs, starts to deviate more strongly from observations. However, for the winter season there is a general improvement in the scores from forecast day 1 to 3 followed by the expected deterioration in the later forecast days. This increase in skill is not likely due to a more favourable large-scale pattern, and probably arises from an improved model performance. For the transition seasons, the three scores do not show much variability during the forecast period.
- It can be concluded that the WRF model, in its present configuration, can be used for the purpose of go/no-go decisions for the launches of the VSB-30 and IO sounding rockets. Even though the focus of this work is on the ESC, the findings reached here are applicable to similar sites in the Arctic/Antarctic region where rockets and balloons are regularly launched such as in Barrow, Alaska and Svalbard archipelago.
- Here the results of just one 5-day simulation for each of the six events is shown. Given the short forecast latency time of these runs, successive simulations initialized at different times before a planned launch will be conducted for real-time launches to help gauge trends in the forecasts and provide further guidance for the go/no-go decision.



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